U.S. DEPARTMENT OF COMMERCE
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PB-274 472

Air Quality Modeling Study to Analyze the Impact of Various SO2 Control Strategies on Ambient Air Quality in the San Francisco Bay Area

Geomet, Inc., Gaithersburg, Md.

Prepared for

Environmental Protection Agency, San Francisco, California. Region IX

Feb 77

PB 274 472

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GEOMET Report Number EF-503
(Revised)

February 1977

AN AIR QUALITY MODELING STUDY TO ANALYZE THE IMPACT OF VARIOUS SO_2 CONTROL STRATEGIES ON AMBIENT AIR QUALITY IN THE SAN FRANCISCO BAY AREA

FINAL REPORT

for

Environmental Protection Agency
Region IX
San Francisco, California

under

Task Number 7
Contract Number 68-02-1442

by

R.C.Koch, D.J.Pelton, P.H.Hwang

Office of Environmental Management

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No. PB274472
4. Title and Subtitle Air Quality Modeling Study to Analyze the Impact of Various SO2 Control Strategies on Ambient Air Quality in the San Francisco Bay Area			5. Report Date February 1977 6.
7. Author(s) Koch, R. C.; Pelton, D. J.: Hwang, P. H.			8. Performing Organization Rept. No. EF-503 (revised)
9. Performing Organization Name and Address Geomet, Incorporated 15 Firstfield Road Gaithersburg, Maryland 20760			10. Project/Task/Work Unit No. Task Number 7 11. Contract/Grant No. 68-02-1442
12. Sponsoring Organization Name and Address US Environmental Protection Agency Region IX San Francisco, CA			13. Type of Report & Period Covered 14. 909/00 f

15. Supplementary Notes

16. Abstracts

Geomet, Inc. was requested by the Environmental Protection Agency to perform a modeling study of the impact of alternative sulfur dioxide emission regulations which may be proposed for the San Francisco Bay Area. The work was performed as a task under a level-of-Effort contract. This report presents the procedures used, the results of the study, and the data used in Volume I. Volume II contains the voluminous information used for model validation, meteorological input data, and some of the model output information.

17. Key Words and Document Analysis. 17a. Descriptors

San Francisco Bay Area, Sulfur Dioxide, ~~Models, Studies~~ Model Studies-Air Pollution, Emission Inventories-CA, Air Pollution Implementation Plan

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 87
10	20. Security Class (This Page) UNCLASSIFIED	22. Price A05 - A01

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ACKNOWLEDGEMENTS

We wish to gratefully acknowledge the helpful cooperation we received from several individuals at the Bay Area Air Pollution Control District offices whose assistance in furnishing data and advice on sources of data was extremely valuable, and especially Thomas Story and Lou Robinson who took time from their already busy schedule to consult with us. We also wish to express our gratitude to Paul Gutfreund of Dames & Moore in Atlanta, Georgia for his willingness to review the point source data which he had collected for the modeling program he had conducted previously.

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GEOMET

Section 1.0

INTRODUCTION

GEOMET, Incorporated was requested by the Environmental Protection Agency to perform a modeling study of the impact of alternative sulfur dioxide emission regulations which may be proposed for the San Francisco Bay Area. The work was performed as a task under a Level-of-Effort contract.

Work began on this task in July 1975 at an organizational meeting at EPA Region IX offices in San Francisco, wherein the purpose and scope of the project were described to all parties concerned; namely representatives from the Bay Area Air Pollution Control District, California Air Resources Board, EPA Region IX, EPA Division of Stationary Source Enforcement, and GEOMET.

This report presents the procedures used, the results of the study, and the data used in Volume I. A summary is given in Section 2.0, and background information is presented in Section 3.0, a description of the model used and the strategies employed are in Section 4.0, the data sources and types of data are described in Section 5.0 and the analysis of the study results are described in Section 8.0.

Volume II contains the voluminous information used for model validation, meteorological input data, and some of the model output information. Specifically, Volume II contains:

Appendix B - SO_2 Monitoring Data

Appendix C - Meteorological Data

Appendix D - Predicted SO_2 Concentrations Statistical Data

Appendix E - Source-Contribution File

Volume II will have limited distribution because it is of limited interest to most readers and because of its bulk.

The original final report published July 1976 has been revised to this current edition in order to reflect changes which were made to four point sources after the original report had been published. The results of the original report have not been altered in any substantial way due to the changes made.

Section 2.0

SUMMARY

The work performed to complete this study has entailed a number of tasks but the most significant effort was directed to four major tasks. They were data collection, model modification and execution, model validation, and evaluation of calculated results.

The data collection effort was conducted in a careful manner to produce the most accurate inventory of emissions which could be provided from existing information. The effort involved in making a deliberate task of collecting valid data was considered worthwhile to ensure that the base of the study was well founded especially after finding that there were significant variations of the reported strength of some of the point sources depending on the origin of the source inventory. A final point source inventory was prepared and reviewed with the proper authorities of the Bay Area Air Pollution Control District. Area source emissions data had been compiled for use in another modeling study and adapted for use in this study. Meteorological data was available from a number of locations. In order to use wind speed and direction data which was representative of conditions in the source-receptor areas, the Bay Area was divided into three regions (Martinez, Richmond, and San Francisco) and a vector average speed and direction was computed for each region using wind data records from monitoring sites which were located within each region.

Some modifications were required to the SCIM program to accept wind data from three regions and to use that data for the appropriate

source receptor combination but still retain the modeling of the entire Bay Area as a single geographic unit in order to account for SO_2 concentrations which may originate in one region but affect receptors in another region.

Model validation was established by comparing average concentrations for 20 days at 21 locations where SO_2 is normally monitored by the BAAPCD or by various industries which are required to maintain a monitoring network. The validation of the model was excellent when considering all 21 locations where the observed SO_2 concentration could be compared with calculated values. The ratio of the predicted to observed concentrations for the entire Bay Area was 1:0. There is more variation as each region is considered separately or as shorter term concentrations are considered. In the Martinez region the predicted to observed ratio was 1.4, in the Richmond area the ratio was 0.4, but in the San Francisco region the ratio is 3.9. Obviously the model performed less favorably in the region where the emissions and the observed values are low.

The evaluation of the proposed strategies has to be considered in terms of the degree of compliance with the air quality standards that is desired. Since almost all of the 120 receptor locations used in this study had calculated values of the 24-hour average concentration which were below the NAAQS of 365 μgm^{-3} and all of them were well below the annual average standard of 80 μgm^{-3}, the merits of each proposed strategy for limiting SO_2 concentrations must be evaluated in terms of the safety margin which is acceptable to EPA and the Bay Area Air Pollution Control District.

Section 3.0

BACKGROUND

The Environmental Protection Agency has proposed to disapprove the sulfur dioxide emission regulation which is currently in effect in the San Francisco Bay Area Air Pollution Control District (BAAPCD). EPA bases the proposed disapproval on the premise that the regulation, as it is presently written, permits optional non-compliance by a source, with the specified emission limitations and therefore does not meet requirements of Section 110(a)(2)(B) of the Clean Air Act. GEOMET, Incorporated was requested by EPA to perform this study to enable EPA to assess the impact of alternative strategies which can be used as guidance in proposing new regulations that contain a specific emission limitation for SO_2 emissions.

3.1 CURRENT REGULATION

Briefly, the current regulation allows a source to emit gases which have concentrations up to 300 ppm of SO_2 but higher concentrations of SO_2 are permitted in the exhaust gases if ambient air quality measurements, which are made outside the property boundaries where the source is located, do not exceed ambient ground-level limits which are stipulated by the current regulation. Pertinent portions of the Bay Area Air Pollution Control District Regulation 2 are reproduced in Appendix A of this report.

It has been EPA policy that sources must be required to comply with emission limitations as the principle means of attaining and maintaining national ambient air quality standards. Since Regulation 2 permits compliance with ambient air limitations as an option to compliance with the specified emission limits, EPA has proposed disapproval.

3.2 PREVIOUS STUDIES

Previous modeling studies have been performed to determine the likelihood of SO_2 concentrations in the ambient air exceeding the established maximum concentrations, but have not been directed toward assessing alternative emission control strategies.

In one such study, sponsored by the Bay Area League of Industrial Associations, Inc. (BALIA), Dames & Moore[1] used computer models to predict the concentrations which would occur on days which were selected to indicate maximum ground-level concentrations. The Dames & Moore study used 1973 and 1974 emissions data as one scenario and a current emission inventory to reflect the changes in the SO_2 burden which would result from the abatement programs which were underway at three companies which were major sources of SO_2. The results of that study indicate that the existing monitors are located close to the position where the maximum concentrations would be predicted to occur, and, that the abatement programs underway would effectively reduce the SO_2 concentrations which will be monitored. The emphasis in the results of the Dames & Moore study is placed on the adequacy of the existing monitoring network to indicate compliance with the NAAQS and not on the ability of the model to predict observed concentrations.

The Dames & Moore Study did recognize but specifically did not address the question of the impact of interruptible natural gas customers on the SO_2 concentration.

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[1] Dames & Moore, June 1975, "Appendix to Comments of the Bay Area League of Industrial Associations."

In another recent study conducted by Environmental Measurements, Inc.[2] and sponsored by EPA Region IX, a mobile laboratory was used to monitor ground-level SO_2 concentrations and overhead SO_2 burden. Surveys were conducted in the industrial corridor in northern Contra Costa County on two days in June 1975. The winds were higher than desirable for a survey of the type attempted and low concentrations were observed throughout the area. Ground-level measurements of total sulfur were measured and reported to range from 71 to 207 ppb in 9 of the 56 plumes monitored, while total sulfur in the remaining 47 plumes was reported to be in the 10-50 ppb range. Typical background levels monitored during these days were 3-5 ppb.

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[2] Environmental Measurements, Inc., June 1975, "Oil Refinery Ground-Level SO_2 Survey," San Francisco, California.

Section 4.0

METHODOLOGY

The best available methodology for relating SO_2 pollutant emissions to ambient air quality requires that both point and area sources be included in an atmospheric simulation model capable of predicting both short- and long-term SO_2 concentrations at any given receptor location. The methodology used must be suitable for assessing the impact of several possible alternatives to the existing regulations which will maintain the ambient air quality standards for SO_2 in the Bay Area. The Sampled Chronological Input Model (SCIM) was selected as the best model currently available for analyzing and predicting the transport and dispersion of pollutants in an urban and surrounding suburban region. SCIM is a steady-state Gaussian plume model which lies, in complexity, between the simple box model and the Gaussian puff trajectory model. Many variations exist in the way the Gaussian plume equation has been implemented. The generality of this equation and its application to urban diffusion analysis has been described by Calder (1970). This basic equation has been shown to be valid over downwind travel distances of up to a few hundred kilometers (e.g., see Slade 1968 and Pasquill 1962). Since 1 to 50 kilometers is the distance scale of primary interest in studying urban air pollution problems and since a great deal of experimental work has been devoted to defining parameters for the Gaussian plume model, this concept has been the principal one used to analyze urban air pollution problems. A brief description of the Gaussian

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plume equation and the modifications applied to it as it is used in SCIM are described below.

4.1 THE GAUSSIAN PLUME EQUATION

Experimental data describing the distribution of concentration in plumes from point sources show that, although wide variations occur, these plumes exhibit a strong tendency toward a Gaussian or normal distribution as a statistical average (Pasquill 1962). To describe this distribution, consider a period of time with a constant point source emission rate of Q (units of mass per unit time) and a constant (in the horizontal plane) mean wind velocity (with magnitude u). In a standard three-dimensional coordinate system with the origin beneath the point source which is at a height h above the ground, the x axis oriented in the direction of the mean wind and the y axis oriented normal to the mean wind direction, the ground-level concentration x is:

$$x = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left\{-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2}\right) + \frac{h^2}{\sigma_z^2}\right\} \tag{1}$$

where

$$\sigma_y^2 = \frac{\int_{-\infty}^{\infty} y^2 \, x \, dy}{\int_{-\infty}^{\infty} x \, dy} \tag{2}$$

$$\sigma_z^2 = \frac{\int_{0}^{\infty} z^2 \, x \, dz}{\int_{0}^{\infty} x \, dz} \tag{3}$$

This relationship satisfies the continuity condition

$$\int_0^{\infty} \int_{-\infty}^{\infty} u \chi \, dy \, dz = Q. \qquad (4)$$

The parameters σ_y and σ_z define the horizontal and vertical dimensions, respectively, of the pollutant cloud in a vertical plane perpendicular to the mean wind velocity. Estimates of σ_y and σ_z as functions of "alongwind" distance from the source give a complete specification of the concentration distribution.

Certain modifications have been introduced in the above equation to account for more realistic boundary conditions. In particular, one such modification is concerned with the marked reduction in vertical diffusion which is caused by a stable layer aloft, in addition to an impervious ground surface. A simple approximation which avoids the use of an infinite series as a solution was developed by Pasquill (1962). At some distance downwind, continued "reflection" of pollutants between the effective mixing ceiling and the ground surface will eventually lead to a uniform vertical distribution. Further reductions in pollutant concentrations will then be due only to crosswind diffusion. Pasquill suggested that the uniform vertical distribution will be approximately achieved at a downwind distance from the source at which σ_z is equal to the height of the effective mixing ceiling. He also suggested that out to a distance at which σ_z is equal to half this ceiling no effect due to "reflection" needs to be considered. If σ_z is represented as a simple power law of x, the following equations follow from these rules:

$$\sigma_z(x) = bx^q, \; x \leq x_1 \tag{5}$$

$$\sigma_z(x) = L, \; x \geq x_2 \tag{6}$$

$$\sigma_z(x) = \frac{L}{2}\left[1 + \left(\frac{x - x_1}{x_2 - x_1}\right)\right] \; x_1 < x < x_2 \tag{7}$$

$$x_1 = \left(\frac{L}{2b}\right)^{\frac{1}{q}}, \; x_2 = \left(\frac{L}{b}\right)^{\frac{1}{q}} \tag{8}$$

where x_1 = distance from source at which $\sigma_z(x) = L/2$

x_2 = distance from source at which $\sigma_z(x) = L$,

L = vertical mixing ceiling,

$\sigma_z(x)$ = vertical diffusion parameter,

x = downwind distance from source, and

b, q = empirical constants.

It may be noted that this approach provides a simple method of using the σ_z concept for all travel distances from a source, and avoids the necessity of changing the diffusion model formulation at critical distances.

The SCIM model contains an option to modify the continuity condition assumed above by an exponential decay factor to account for various pollutant removal processes in the atmosphere. With a pollutant half-life of t_{50} and a decay time of x/u, equation (1) with the decay factor included becomes:

$$x = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left\{-\frac{y^2}{2\sigma_y{}^2} - \frac{0.693x}{t_{0.5}u} - \frac{h^2}{2\sigma_z{}^2}\right\} \tag{9}$$

where

x = concentration (mass/unit volume)

Q = source emission rate (mass/unit time)

u = mean wind speed (distance/unit time)

σ_y = standard deviation of the horizontal displacement of pollutants in the crosswind direction (distance)

σ_z = standard deviation of the vertical displacement of pollutants (distance)

x = horizontal coordinate in mean wind direction (distance)

y = horizontal coordinate in crosswind direction (distance)

$t_{0.5}$ = pollutant half-life (time)

h = effective height of the source (distance)

0.693 = natural logarithm of 2

In this study it was assumed that there is no significant decay of sulfur dioxide (i.e., t_{50} is very large).

4.1.1 Plume Rise

It is characteristic that emissions are released from a stack in order to reduce their polluting effect in the immediate vicinity and in the nearby downwind area. In general, these emissions must also be hot and fast-moving for the stack to discharge its effluents adequately. As a result, they leave the stack with a considerable amount of upward momentum and thermal buoyancy. The effluent gases are accelerated upward; however, the upward momentum is continually diluted due to turbulent mixing with the ambient air. The resulting effect is a general leveling off of the effluent plume at some distance downwind.

Several formulas have been developed to predict the plume rise effect. A comprehensive review of these formulas and available plume rise observations by Briggs (1969) resulted in a set of recommended formulas which are simplifications and combinations of previous findings. The following recommended formulas are obtained from his conclusions:

$$h = H_s + \Delta H \tag{10}$$

where

h = effective stack height (m)

H_s = physical stack height (m)

ΔH = plume rise. (m)

For stable conditions (Pasquill stability class E)

$$\Delta H = 2.9 \left(\frac{F\ T_a}{0.03034\ u}\right)^{0.33} \tag{11}$$

where

F = buoyancy flux parameter (m^4/sec^3)

T_a = ambient air temperature (^oK)

u = wind speed at stack height (m/sec)

$$F = 2.45 \left[1 - \left(\frac{T_a}{T_s}\right)\right] V_s D_s^2 \tag{12}$$

where

T_s = stack gas temperature (°K)

V_s = stack gas exit speed (m/sec)

D_s = stack diameter (m).

For neutral and unstable conditions (Pasquill stability classes A through D).

$$\Delta H = \frac{3.75F^{0.33}X^{0.67}}{u} \tag{13}$$

where

$$X = \begin{cases} 2.16F^{0.4}H_s^{0.6} & ,H_s \leq 305 \\ 67.3F^{0.4} & ,H_s \geq 305 \end{cases} \tag{14}$$

H_s = stack height (m).

Certain limitations in the use of these formulas were noted by Briggs. In flat and uniform terrain, he concludes that observed plume rise may deviate from Equation (13) by $\pm$ 10 percent; in the vicinity of substantial terrain steps or near a large body of water, the deviations may be $\pm$ 40 percent. These findings relate to neutral stability conditions. In unstable conditions, the deviations may be larger and occur somewhat irregularly; however, the data presented by Briggs are not adequate to quantify this. With regard to stable conditions, the data presented by Briggs suggest that deviations in the nondimensional rise (i.e., $\Delta h/(F/us)^{0.33}$) as large as $\pm$ 0.5 may occur. When compared with his recommended mean nondimensional plume rise of 2.9, this

deviation shows that variations of ± 17 percent from Equation (11) have been observed in the developmental data.

4.1.2 Wind Speed and Direction

The model hypothesizes the existence of a mean wind speed and direction; therefore, data must be obtained which are suitable for defining these means. In many urban areas, wind monitoring equipment is installed simultaneously with air quality monitoring equipment. As a result it is frequently possible to consider wind observations from several representative points which can be vectorially averaged to obtain a mean wind direction and speed as has been done in this study.

Since wind speeds near ground level under certain conditions show considerable increase with height, it is desirable to account for the increased transport speed associated with emissions from sources with large effective heights. The wind profile may be represented empirically in the lowest layers of the atmosphere by a power law (e.g., Munn 1966) as follows:

$$u(z) = u_1 \left(\frac{h}{h_1}\right)^a \qquad (15)$$

where

$u(z)$ = wind speed at height z,

u_1 = reported wind speed,

a = empirical wind profile parameter.

h = effective stack height (m)

h_o = observing height (m)

Values of "a" are assigned in SCIM on the basis of the computed stability class using the correspondence shown in Table 1.

Table 1. Wind Speed Profile Exponents

Atmospheric Stability Class	Wind Speed Profile Exponent
Unstable (A,B,C)	0.10
Neutral (D)	0.17
Stable (E,F)	0.25

Because of the large area modeled in this study, the area was divided into three components with separate hourly wind directions and speeds determined for each component, as described further in Section 4.4. The areas and the wind data used to represent them are described in Section 5.3.

4.1.3 Diffusion Parameters

A large number of empirical functions have been proposed by investigators to represent the diffusion parameters σ_y and σ_z. In each set of σ_y and σ_z parameters, the values vary with the stability of the

atmospheric boundary layer. Two sets of diffusion parameter values, one from Pasquill (1962) for rural conditions and one from McElroy and Pooler (1968) for urban conditions, and the associated meteorological parameters used to characterize stability are used in the SCIM program.

This study is based on the diffusion parameter values relevant to an urban environment provided by McElroy and Pooler (1968). Their study characterized observed values of σ_y and σ_z from continuous tracer emissions in the city of St. Louis according to several systems of meteorological stability classification. The system of stability classification which was selected for SCIM is based on the Pasquill stability classes. This system can be evaluated from conventional airport data using a method suggested by Turner (1964), which is described in Tables 2 and 3. The solar altitude (e.g., Sutton 1953) required in this system may be computed by the following formula:

$$\alpha = \arcsin \left[\sin\phi \sin\delta + \cos\phi \cos\delta \cos\left[\frac{\pi}{12}(h-12)\right]\right] \tag{16}$$

$$\delta = 23.5\left(\frac{\pi}{180}\right) \sin\left\{\frac{\pi}{180}\left[30(m-1) + d - 80\right]\right\} \tag{17}$$

where

α = solar altitude

δ = solar declination

m = month of year

d = day of month

h = hour of day

ϕ = latitude.

Table 2. Meteorological Stability Classifications for Characterizing the Diffusion Parameters (σ_y and σ_x)

Wind Speed (Knots)	Stability Class for Indicated Net Radiation Index *						
	4	3	2	1	0	-1	-2
0, 1	A	A	B	C	D	E	E
2, 3	A	B	B	C	D	E	E
4, 5	A	B	C	D	D	E	E
6	B	B	C	D	D	E	E
7	B	B	C	D	D	D	E
8, 9	B	C	C	D	D	D	E
10	C	C	D	D	D	D	E
11	C	C	D	D	D	D	D
≥12	C	D	D	D	D	D	D

*Net Radiation Index Values are Given in Table 3.

Table 3. Net Radiation Index Values

Time of Day	Total Cloud Amount (t)	Ceiling (c), (ft)	Net Radiation Index for Indicated Solar Altitude (a)			
			$a \leq 15^\circ$	$15^\circ \leq a \leq 35^\circ$	$35^\circ \leq a \leq 60^\circ$	$a > 60^\circ$
Night	$t \leq 0.4$	--	-2	--	--	--
Night	$0.4 < t < 1.0$	--	-1	--	--	--
Night	$t = 1.0$	$c < 7,000$	0	--	--	--
Night	$t = 1.0$	$c \geq 7,000$	-1	--	--	--
Day	$t < 1.0$	$c \geq 16,000$	1	2	3	4
Day	$0.5 < t < 1.0$	$c < 7,000$	1	1	1	2
Day	$0.5 < t < 1.0$	$16,000 > c \leq 7,000$	1	1	2	3
Day	$t = 1.0$	$c \leq 7,000$	0	0	0	0
Day	$t = 1.0$	$16,000 > c \geq 7,000$	1	1	1	2
Day	$t = 1.0$	$c \geq 16,000$	1	1	2	3

The diffusion parameters presented by McElroy and Pooler (1968) are shown in Figures 1 and 2. The relationships presented graphically by McElroy and Pooler have been fitted to power laws for use in SCIM. The curves have been extrapolated from 600 to 10 meters as shown in Figures 1 and 2. The fitted equations have the forms,

$$\sigma_y = ax^p \tag{18}$$

$$\sigma_z = bx^q \tag{19}$$

The values obtained for a, b, p, and q are given in Table 4.

Table 4. Fitted Constants for Urban Diffusion Parameters Based on Turner Stability Classifications

Stability Index	Crosswind Constants (1)		Constants for Vertical Diffusion Parameter (2)			
			$x \leq 600$		$x \geq 600$	
	a	p	b	q	b	q
A (3)	-	-	-	-	-	-
B	1.42	0.745	0.0926	1.18	0.0720	1.22
C	1.26	0.730	0.0891	1.11	0.169	1.01
D	1.13	0.710	0.0835	1.08	1.07	0.682
E	0.992	0.650	0.0777	0.955	1.01	0.554

(1) $\sigma_y = ax^p$, where x is downwind distance from source; σ_y and x are in meters.
(2) $\sigma_z = bx^p$; σ_z and z are in meters.
(3) Not available from McElroy and Pooler data; use Class B values.

4.1.4 Mixing Height

The vertical mixing ceiling is defined as that height above ground level at which there is a marked reduction in vertical diffusion. Such barriers are observed as a sharp drop in the concentration observed in a vertical sounding (e.g., Davidson 1967). It may be observed as a

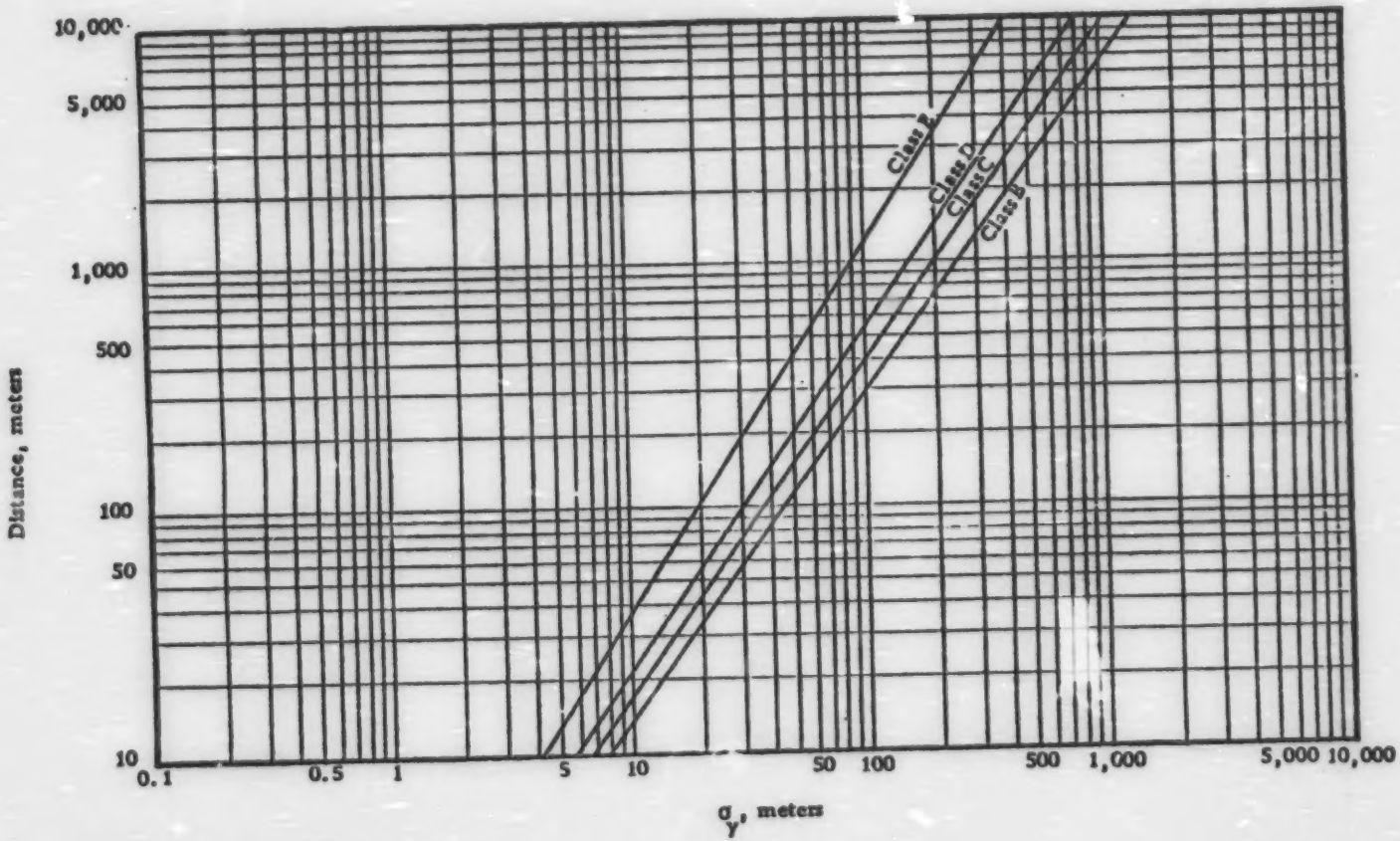


Figure 1. Urban σ_y Diffusion Parameter

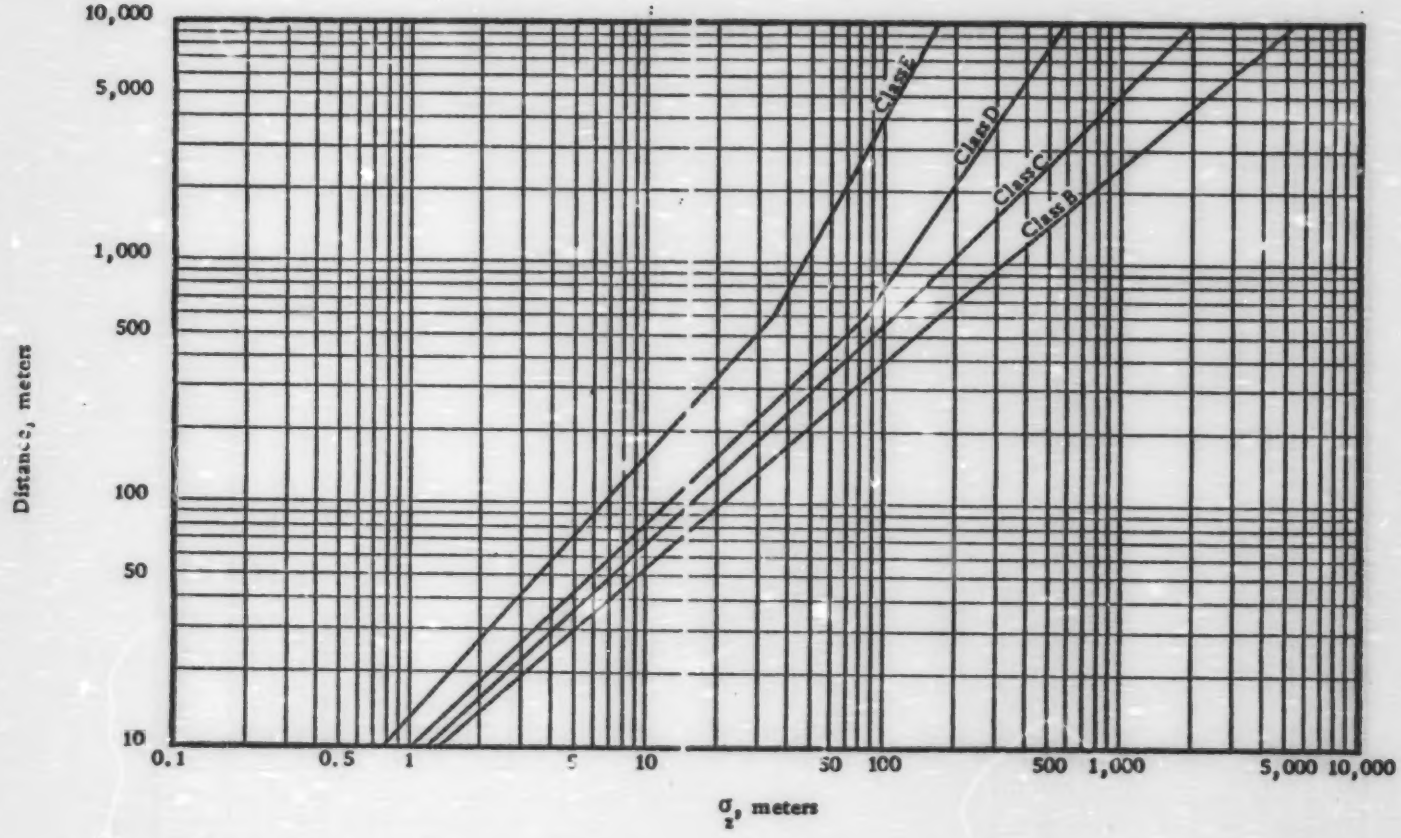


Figure 2. Urban σ_z Diffusion Parameter

delineation between the smoke-filled layer and cleaner air aloft over many cities in the early morning. Much higher ceilings typical of afternoon hours are clearly visible to air travelers in climbing to or descending from cruising altitudes. The ceiling may vary from 100 meters at night to over 1500 meters during the day. Hourly estimates of the ceiling are required for use in the model.

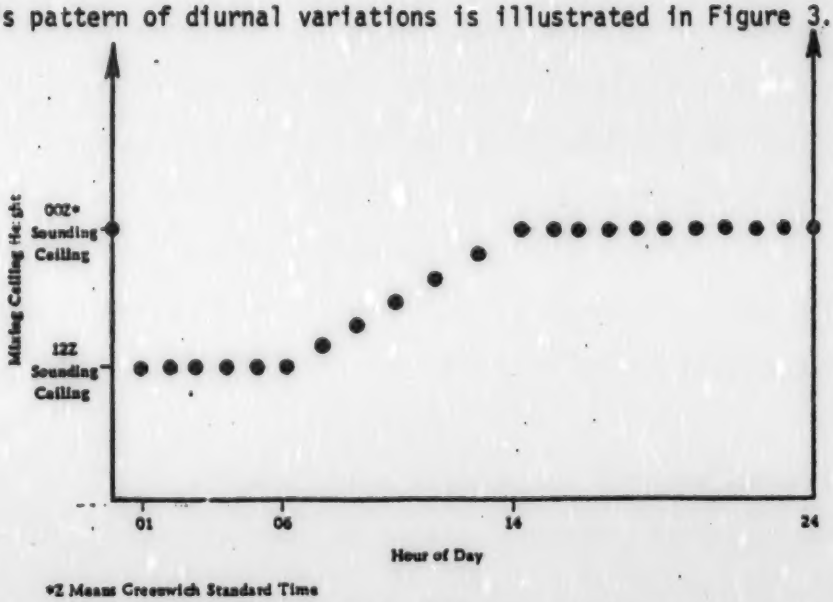
Unfortunately, this mixing ceiling is not always visibly discernible and no routine systems for taking vertical soundings of pollutant materials are in operation. Therefore, the ceiling is generally inferred from temperature soundings which are routinely observed twice daily at certain airports by the National Oceanic and Atmospheric Administration (NOAA). These observing locations are separated by about 200 kilometers on the average and are usually located outside the urban area. The mixing layer is generally characterized by a near adiabatic lapse rate extending from the ground to some altitude above which a deep (several kilometers) more stable lapse rate exists. However, the vertical temperature structure of the atmosphere is frequently not this well defined. As a result, considerable judgment may be required to define where, in a vertical temperature profile, an effective mixing ceiling exists. Unfortunately very little data have been collected on the relationship between vertical pollution and temperature profiles which could be used to develop and substantiate rules for defining the mixing ceiling over an urban region.

The procedure which is generally used to define the mixing ceiling is the following: Determine the general rural vertical temperature

profile from the nearest appropriate (same air mass) radiosonde, or by interpolation of two or more nearby radiosondes. Estimate minimum morning and maximum afternoon air temperatures which are representative of the urban area. The afternoon temperature may be obtained directly from airport observations or other available data. In most cases the morning urban temperature will exceed the rural temperature. Construct adiabatic temperature profiles from the urban temperatures which intersect the rural temperature profile. The heights of these intersections are assumed to be the minimum and maximum mixing ceilings. A method of interpolating between these values to give hourly estimates is to:

1. Use the morning minimum from midnight to 6 a.m.
2. Linearly interpolate between the minimum and the maximum between 6 a.m. and 2 p.m.
3. Use the afternoon maximum between 2 p.m. and midnight.

This pattern of diurnal variations is illustrated in Figure 3.



*Z Means Greenwich Standard Time

Figure 3. Graphical Model of Procedure Used to Interpolate in Time Between Mixing Ceiling Estimates Obtained for Standard Radiosonde Observing Times

Limited simultaneous observations of temperature and SO_2 on particle concentration profiles reported by Davidson (1967), Roberts et al. (1970) and McCaldin and Sholtes (1970) attest to the general validity of this approach.

Several methods of implementing this approach and for interpolating between radiosonde observations both in space and time have been reported by Holzworth (1967), Roberts et al. (1970) and Ludwig et al. (1970). These investigators have also differed in the technique used to estimate representative urban temperatures which frequently are not recorded routinely. The choice among these details should most appropriately be governed by the nature of the data with which the model will be used.

Mixing heights were obtained from the radiosonde observations at Oakland International Airport.

4.1.5 Decay of Sulfur Dioxide

Atmosphere removal processes are approximated in the model by an exponential decay of the pollutant with travel time. The removal processes are parameterized by specifying a pollutant half-life. However, due to the limited data and the wide variety of removal processes which may be operating, it is difficult to define an appropriate half-life.

Information regarding SO_2 removal processes consists of atmospheric and laboratory experiments (reviewed by Urone and Schroeder 1969), comparisons of SO_2 concentrations with other materials in the atmosphere (e.g., Weber 1970, 1971 and Manowitz et al. 1970), and less

direct comparisons of observed SO_2 concentrations and other tracer materials with model computations.

The general conclusion drawn from this evidence is that the SO_2 half-life under various defined atmospheric conditions can range from 10 minutes to several days, with several hours being a preferred range under many urban conditions (a nominal value of four hours has been used in many previous studies). Validation studies with SCIM on SO_2 data have shown useful results assuming negligible decay. No decay is assumed in this study.

4.2 THE GAUSSIAN PLUME EQUATION FOR MULTIPLE SOURCES

The basic Gaussian plume model describes the concentration field from a single point source during a short-term (i.e., steady-state) period. However, in an urban environment it is often necessary to consider emissions from many small sources (e.g., residential heating units), in numbers too large to treat each source individually. As a practical matter, individual large sources whose emission rates are significantly greater than other sources in the general vicinity are treated as point sources. The remaining emissions are treated as an area source whose emission rate and effective height are specified as a function of horizontal position using appropriate emission inventory techniques. As described by Calder (1970), it is a simple matter to adapt the point source model to an area source. First, consider a reorientation of the coordinate system so that the origin is at a receptor point of interest and the x axis is pointed upwind into the mean wind direction. In this

coordinate system, Equation (9) gives the concentration at the receptor from a point source with horizontal coordinates (x, y).

Let q dx dy be the total amount of pollutant emitted per unit time in a horizontal element of area dx dy. Assuming that the total concentration at a receptor is the sum of concentration contributions from all individual area source elements, the concentration, x_A, at the receptor location due to the area source is:

$$x_A = \int_0^{x_1} \int_{y_1}^{y_2} \frac{q(x, y)}{\pi u(h_A)\sigma_y(x)\sigma_z(x)} \exp\left\{ - \frac{y^2}{2\sigma_y^2(x)} - \frac{h_A^2}{2\sigma_z^2(x)} - \frac{0.693x}{t_{50}u(h_A)} \right\} dy\, dx \qquad (20)$$

where

h_A = effective area source emission height,

$q(x, y)$ = area source emission rate per unit area,

x_1 = distance to most upwind portion of emission area, and

y_1, y_2 = distances to furthermost crosswind portions of emission area.

The integration operation required to calculate concentrations from area sources is performed by using the "narrow plume" assumption. Mathematically, it requires that $\bar{q}(x)$ be defined such that

$$\frac{1}{\sigma_y(x)} \int_{y_1}^{y_2} q(x,y) \exp\left\{-\left[1/2 \frac{y}{\sigma_y(x)}\right]^2\right\} dy = \sqrt{2\pi}\, \bar{q}(x). \qquad (21)$$

This will be generally true as long as the spatial distances between variations in area-source emission rates $q(x,y)$ are large compared to the horizontal diffusion parameters $\sigma_y(x)$. It is assumed that

$$\bar{q}(x) \approx q(x,o). \qquad (22)$$

As a result, Equation (20) becomes

$$\chi_A = \sqrt{\frac{2}{\pi}} \int_o^{x_d} \frac{\bar{q}(x)}{u\sigma_z(x)} \exp\left\{-1/2\left[\frac{h}{\sigma_z(x)}\right]^2\right\} dx . \qquad (23)$$

This equation is evaluated using a slight variation of the trapezoid rule in which small increments in x are gradually increased with increasing x to a uniform increment. This allows the larger variations in the integrand which tend to occur with small, rather than large, x to be more accurately evaluated.

The concentration χ_p at a receptor point due to N point sources is given by:

$$\chi_p = \sum_{i=1}^{N} \left[\frac{Q_i}{\pi u(h_i)\sigma_y(x_i)\sigma_z(x_i)} \exp\left\{-\frac{y_i^2}{2\sigma_y^2(x_i)} - \frac{0.693\, x_i}{t_{50} u(h_i)} - \frac{h_i^2}{2\sigma_z^2(x_i)}\right\}\right] \qquad (24)$$

where the subscript i denotes values for the ith point source.

Equations 23 and 24 give the concentrations from area and point sources in an urban area during a single quasi steady-state period. The total concentration is given as the sum of that from the area and the point sources.

The basic model described thus far defines the urban concentration field for a single quasi steady-state period. However, mean concentrations over long-term periods during which both emission and meteorological conditions are significantly variable are also of interest. The short-term model is used to estimate long-term concentrations by assuming that the long-term period may be resolved into a succession of short-term quasi steady-state periods. This assumption is basic in the long-term models which have been developed by various investigators.

The model can be used to represent diurnal variations in both emission rates and meteorological characteristics. In this study an hourly emission rate (which is the same for each day of the year) was obtained for each area source from available emission inventory data. In addition, monthly variations in the emission rates of power plants were available from the emission inventory and are used in the model.

SCIM reduces the calculations required to estimate long-term mean concentrations by statistically sampling the quasi steady-state periods which make up the long-term period. Concentrations calculated for the selected periods are averaged to obtain the long-term mean concentration. These calculations are used to approximate the frequency distribution of short-term concentrations over the long-term period, by

ordering the concentrations from lowest to highest value. This approach has been applied with considerable success (see Koch and Thayer 1971 and Koch and Fisher 1973). It has been shown that statistical sampling can reduce the calculations required for seasonal concentrations by 90 percent or more. The expected annual maximum short-term concentration may be determined from the frequency distributions or by means of the geometric standard deviation (e.g., see Larsen 1972). The calculations are made for specified receptor locations. Since the geometric standard deviation is determined for specific locations using hourly concentrations generated by the model, the statistical extrapolation is not influenced by existing characteristics of source emission rates and spatial distributions of sources. Any changes in the sources which are input to the model are reflected in the computed geometric standard deviations.

4.3 CONTROL STRATEGIES EVALUATED

The overall objective of the program was to determine the impact of several alternatives to the control strategy which may be imposed. The control strategies which were evaluated limit process source emissions to no greater than 300, 500, 1000, or 2000 ppm or limit the sulfur content of the fuel in combustion sources to 0.3, 0.5, 0.7, and 0.9 percent sulfur. As a further consideration, one alternative was to assume the power generating plants switched entirely to 0.5 percent sulfur fuel oil and did not use natural gas. The impact of natural gas curtailment to interruptible customers could not be evaluated in the computer model due to a lack of specific information regarding the customers whose service was interrupted in the model year (1973), and the amount and type of

replacement fuel. Estimates of the impact of natural gas curtailment are considered in a subjective manner after the computer model output has been evaluated.

To determine the impact of the proposed control strategies a source-contribution file was established within the computer. The source-contribution file provides a record of the amount of SO_2 contributed by each source to each receptor. Using the source-contribution file, the SO_2 contributed to each receptor was modified to reflect the impact of any reduction in SO_2 emissions which might be imposed on that source. For example, if a given process source presently emits SO_2 at a concentration of 2000 ppm and the alternative being evaluated is 1000 ppm, then the contribution of that source to any receptor was reduced by one-half. In applying the control alternatives to process sources no increases in SO_2 emissions were permitted, i.e., a source currently emitting 500 ppm SO_2 was not allowed to increase to 1000 ppm, but those process sources which are currently emitting above a proposed alternative were reduced to the alternative being evaluated. For combustion sources, the SO_2 contributions were allowed to increase if the sulfur content of the fuel currently used is less than the sulfur content of one of the strategy alternatives.

4.4 PREPARING AND RUNNING THE MODEL

Several modifications were made to the SCIM model to adapt it more specifically to the San Francisco study. These changes were made to accept the input data in the available format, to allow the meteorological data to be represented in three data sets, to reflect time variations of

the SO_2 sources and to permit evaluation of the specific alternatives in control strategies which were proposed for this task.

The first of these modifications involved a brief study of how best to characterize the meteorological input to the program. In many studies a problem may arise from having too little meteorological data. In this study there were many stations with wind speed and direction measurements from which to select data for the model input. The observations reflect the complex wind patterns of the Bay Area, and wind directions frequently differ by 90 degrees among various stations. We decided to model the Bay Area as three separate regions which represented logical geographical grouping of the SO_2 sources and wind monitoring stations. The three regions used in modeling the Bay Area are shown in Figures 4, 5, and 6 in Section 5.3. Although each source region is modeled separately, the effects of each region are advected into neighboring areas. The SO_2 concentration calculated for each receptor location may have contributions from all three regions. Concentration contributions from each region are based on the wind speed and direction which were defined for the source region. Since mixing height data was available only from Oakland Airport the same mixing height data was applied to all regions. Likewise, the stability index was determined using cloud observations and wind speeds from the Oakland Airport.

Several special purpose programs or program changes were written for this study. The wind speed and direction for each region were computed by means of a program to calculate the vector average of stations located within each region. The model was modified to accept monthly variations

for the power plant emissions and hourly variations of the area source emissions. A special preprocessing program was written to convert the area source emissions data from the code compatible with a CDC computer to a code compatible with the IBM computer used by GEOMET. The model was also modified to calculate any reductions in emission rates necessary to meet one of the alternatives being evaluated. A fraction of the current emission rate was determined for each source for each strategy. That fraction was applied to the source-contribution file to evaluate each strategy.

After the model was run to provide enough information to judge how well the model will predict SO_2 concentrations in the Bay Area, the final computer run was made. The final run included predictions of the 24-hour average concentration made for every other day in 1973. The 24-hour average is calculated by averaging 8 one-hour concentrations made for that day. Using 8 values to estimate the 24-hour average will make a good estimate of the 24-hour average but if the predictions are biased from this approach they are usually biased toward the higher concentrations.

Section 5.0

DATA BASES

A significant portion of the effort required for this study was spent in preparing the data which constitute the model input and the observations against which the model predictions are compared. The data preparation is discussed under three subject headings: source inventory, SO_2 monitoring data, and meteorological data. A special effort was made at the beginning of this study, by interviewing the air pollution authorities in the Bay Area, to identify any data that might be considered to be of poor quality. Any data so identified were not included in this study.

5.1 SOURCE EMISSION INVENTORY

Source inventory data were obtained for the point and area sources in the Bay Area from the Bay Area Air Pollution Control District. All of the data used in this study represent that which is felt to be the best available for use in this application.

5.1.1 Point Source Data

The final set of point source data is the result of an intensive effort to identify all the major point sources and then determine from the several sets of data which is the most representative for this modeling application. Initially, it was anticipated that the NEDS files would provide the inventory of emission points, the source strength and stack parameters necessary for this work. Examination of the NEDS files showed that an extensive list of companies was entered in the file but most of the necessary data was missing, e.g., the emission rate and/or the stack parameters.

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A list of the information available from the NEDS file was compiled, however, as a cross reference to the data being collected elsewhere.

Another source of point source data existed in a draft working paper form, the author and reference of which were not clearly identified initially. Later in the project the author of that paper was identified and contacted to determine the sources of the information reported. As a result, it was possible to use this data to supplement other sources and to help resolve conflicts among alternative sources of data.

The source inventory publication produced by the BAAPCD[3] provided the most complete list of the major sources and the average quantity of SO_2 emitted by each company. However, individual stack data were not available from that publication.

A previous air quality modeling study performed by Dames & Moore was furnished by the Project Officer as soon as it became available. Since the source data contained in that report were developed for a modeling study, it was already in a useable form for this study. Subsequent discussions with the author of the Dames & Moore[4] study helped resolve questions of the validity of that data. A comprehensive list of the data obtained from each of the last three data sources (excluding NEDS) was compiled and sent to the authorities at the BAAPCD with a request that the information be reviewed for validity and completeness. It was felt that this review would be necessary due to the large variations in the emission rates

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[3] Bay Area Air Pollution Control District, 1973, "Source Inventory of Air Pollutant Emissions in the San Francisco Bay Area

[4] Dames & Moore, June 1975, "Appendix to Comments of the Bay Area League of Industrial Associations."

reported for some of the companies with SO_2 emissions. The result of that review produced an expanded list of companies which would be included in the study and a nearly final list of the source strength of each emission source. A final sorting of the data was required to identify which sources were due to combustion of fuels and which are process sources. For the combustion sources, the sulfur content of the fuel was determined to the extent possible. The data for power plants was readily available from the Form 67 which was submitted to the Federal Power Commission. The SO_2 emission rates used in this study for the power plants were determined by applying emission factors to the fuel use data given on FPC Form 67. Since the quantity and type of fuel used is listed for each month, a monthly variation factor was calculated for the emission rate on each of the sources representing a power plant.

Variation factors were not available for 1973 for process sources or combustion sources other than power plants. This is judged not to be a serious limitation on this study since monthly variations available for some sources for 1974 are very small.

The point source data presented in Table 5 are the 41 sources which were input to the model. In some instances when there were identical sources at a plant, two or three stacks were combined and modeled as one. This was only done with combustion sources in cases where the strategy would not require a reduction in exhaust gas concentrations to comply with the 300 ppm emission regulation. The headings in the table are: VEL (exhaust gas velocity, meters per second), Q (source strength, grams per second), DIA (stack diameter, meters), TEMP (exhaust gas

temperature, degrees Kelvin), sulfur content of fuel used in combustion sources (percent), source type (where 1 = process, 2 = non-utility combustion, 3 = power plant combustion), and the last column is the stack SO_2 concentration in ppm using the 1973 emission rate data.

The data presented in Table 5A reflect 1973 operating conditions. For evaluation of the control strategies seven sources were modified to reflect the reduced emissions due to abatement programs which have been initiated since 1973. The modifications made to the source strength were: source 3, Q reduced from 87 $g\text{-}sec^{-1}$ to 12.7; source 4 reduced from 79.8 to 0.0; source 5 reduced to 0.0 from 54.6; sources 9 and 10, Q reduced from 122.0 and 64.2 $g\text{-}sec^{-1}$ to 0.0 each; sources 15 and 16 Q reduced from 210.0 $g\text{-}sec^{-1}$ each to 21.0 each, these changes are shown in Table 5b.

5.1.2 Area Source Data

Area source data used in this program were received from the BAAPCD on a magnetic tape in a form which provided the emission rate in grams per second for each grid square (5 kilometers on a side) in the Bay Area. The area source data were compiled for a modeling study performed by the Lawrence Livermore Labs. The SO_2 data contained on that tape were checked against the 1973 source inventory published by the BAAPCD and agreed closely with data for the whole Bay Area and with data for San Francisco County. The area source data had been adjusted to a seasonal variation which represents July, August, and September. Emission rates were given for each hour of the day which reflected an hourly factor which was not the same for each grid square. In adapting this data for use in the SCIM model, it was necessary to determine an hourly variation

Table 5a. Point Source Data Input to SCIM for Model Validation

	Source No.	VEL M/S	Q G/S	DIA M	TEMP DEG K	Sulfur Content Percent	Source Type	SO_2 Concentration (ppm)
Standard Oil	1	27.00	74.00	3.10	540.00	0.0	1	251
Standard Oil	2	4.00	91.00	0.80	573.00	0.0	1	33248
Allied Chemical - Richmond	3	8.60	87.00	1.83	347.00	0.0	1	1711
Allied Chemical - Richmond	4	25.70	79.80	1.06	394.00	0.0	1	1777
Allied Chemical - Richmond	5	21.20	54.60	1.06	354.00	0.0	1	1324
EXXON	6	20.80	421.00	4.60	597.00	0.0	1	982
Collier Chemical	7	15.00	27.70	4.57	1512.00	0.0	1	218
Collier Chemical	8	10.30	26.50	4.57	1144.00	0.0	1	230
Union Oil	9	16.10	122.00	0.84	816.00	0.0	1	14305
Union Oil	10	19.50	64.20	0.84	744.00	0.0	1	5667
Shell Oil - Martinez	11	10.00	51.70	5.40	641.00	0.0	1	186
Shell Oil - Martinez	12	6.60	35.80	5.40	566.00	0.0	1	172
Shell Oil - Martinez	13	12.90	106.40	3.00	641.00	0.0	1	959
Shell Oil - Martinez	14	23.50	41.20	2.40	602.00	0.0	1	299
Monsanto - Avon	15	3.30	210.00	1.82	673.00	0.0	1	21105
Monsanto - Avon	16	18.10	210.00	0.91	339.00	0.0	1	7753
Phillips - Avon	17	27.50	70.60	3.05	537.00	0.0	1	242
Phillips - Avon	18	19.50	66.30	3.60	520.00	0.0	1	223
Phillips - Avon	19	13.50	29.50	3.05	472.00	0.0	1	181
Stauffer Chemical	20	8.50	168.00	2.30	319.00	0.0	1	1945
Allied Chemical - Bay Point	21	3.78	49.90	1.98	339.00	0.0	1	1863
Sequoia Refinery	22	7.20	5.50	0.90	478.00	0.0	2	736
Sequoia Refinery	23	7.20	5.50	0.90	478.00	0.0	2	736
Fibreboard	24	8.00	1.30	2.74	353.00	0.0	2	13
Fibreboard	25	9.10	1.70	2.74	353.00	0.0	2	14
Glass Container	26	2.06	1.80	2.13	644.00	0.0	1	208
PG&E - Oleum	27	12.00	0.21	1.73	519.00	0.50	3	5
PG&E - Martinez	28	14.00	18.28	1.73	505.00	0.50	3	360
PG&E - Avon	29	14.00	3.44	1.73	505.00	0.40	3	68
PG&E - Contra Costa	30	11.34	0.41	3.35	447.00	0.50	3	2
PG&E - Contra Costa	31	10.30	1.35	4.72	390.00	0.50	3	4
PG&E - Contra Costa	32	53.66	24.69	8.26	405.00	0.50	3	5
PG&E - Pittsburg	33	19.90	37.21	3.35	392.00	0.50	3	107
PG&E - Pittsburg	34	20.90	25.84	4.27	371.00	0.50	3	41
PG&E - Pittsburg	35	25.50	25.78	6.10	385.00	0.50	3	17
PG&E - Hunters Point	36	10.12	2.04	4.98	475.00	0.50	3	6
PG&E - Hunters Point	37	25.45	3.06	3.51	437.00	0.50	3	7
PG&E - Potrero	38	16.06	4.20	3.35	366.00	0.45	3	14
PG&E - Potrero	39	1.83	0.46	7.32	433.00	0.45	3	3
Standard Oil	40	2.55	2.63	1.80	588.00	0.0	1	306
Standard Oil	41	0.64	1.14	2.40	589.00	0.0	1	297

Table 5b. Point Source Data Input to SCDM for Strategy Evaluation

	Source No.	Stack Height (m)	VEL M/S	Q G/S	DIA M	TEMP DEG K	Sulfur Content Percent	Source Type	SO_2 Concentration (ppm)	UTM Coordinates (x)	(y)
Standard Oil	1	79.9	27.00	74.00	3.10	340.00	0.0	1	231	553.2	4199.1
Standard Oil	2	45.1	4.00	91.00	0.80	575.00	0.0	1	13248	554.0	4198.5
Allied Chemical - Richmond	3	45.7	8.60	12.70	1.83	347.00	0.0	1	1711	554.7	4199.1
Allied Chemical - Richmond	4	45.7	25.70	0.0	1.06	394.00	0.0	1	1777	554.7	4199.1
Allied Chemical - Richmond	5	45.7	21.20	0.0	1.06	394.00	0.0	1	1334	554.7	4199.1
EXXON	6	139.9	20.80	421.00	4.60	397.00	0.0	1	932	576.0	4214.0
Collier Chemical	7	45.7	15.00	27.70	4.57	1312.00	0.0	1	218	566.0	4207.3
Collier Chemical	8	45.7	10.30	26.50	4.57	1144.00	0.0	1	250	566.0	4207.3
Union Oil	9	30.5	16.10	0.0	0.84	816.00	0.0	1	14308	565.9	4210.4
Union Oil	10	51.3	19.80	0.0	0.84	744.00	0.0	1	5667	565.9	4210.4
Shell Oil - Martinez	11	106.1	10.00	51.70	5.40	641.00	0.0	1	186	577.4	4208.5
Shell Oil - Martinez	12	106.1	6.60	35.80	5.40	566.00	0.0	1	172	577.4	4208.5
Shell Oil - Martinez	13	106.1	12.90	106.40	3.00	641.00	0.0	1	939	577.4	4208.5
Shell Oil - Martinez	14	48.8	23.90	41.20	2.40	602.00	0.0	1	299	577.4	4208.5
Monsanto - Avon	15	102.1	3.30	21.00	1.82	673.00	0.0	1	21105	582.9	4208.7
Monsanto - Avon	16	102.1	18.10	21.00	0.91	139.00	0.0	1	7733	582.9	4208.7
Phillips - Avon	17	73.0	27.90	70.60	3.08	537.00	0.0	1	342	581.4	4209.4
Phillips - Avon	18	73.0	19.50	66.30	3.60	520.00	0.0	1	223	581.4	4209.4
Phillips - Avon	19	104.9	13.50	29.50	3.05	472.00	0.0	1	181	581.4	4209.4
Stauffer Chemical	20	61.0	8.30	61.00	2.30	319.00	0.0	1	1945	577.9	4209.9
Allied Chemical - Bay Point	21	41.1	3.78	49.90	1.98	339.00	0.0	1	1863	588.0	4211.1
Sequoia Refinery	22	30.5	7.20	5.50	0.90	478.00	0.0	2	736	562.7	4208.0
Sequoia Refinery	23	30.5	7.20	5.50	0.90	478.00	0.0	2	736	562.7	4208.0
Fiberboard	24	15.2	8.00	1.30	2.74	353.00	0.0	2	13	608.7	4208.4
Fiberboard	25	45.7	9.10	1.70	2.74	353.00	0.0	2	16	608.7	4208.4
Glass Container	26	10.7	2.06	1.80	2.13	644.00	0.0	1	208	603.5	4208.5
PG&E - Gleam	27	76.2	12.00	0.21	1.73	519.00	0.50	3	5	565.3	4210.8
PG&E - Martinez	28	61.0	14.00	18.28	1.73	505.00	0.50	3	360	577.8	4209.8
PG&E - Avon	29	61.0	14.00	3.44	1.73	505.00	0.40	3	68	580.0	4211.0
PG&E - Contra Costa	30	61.0	11.34	0.41	3.35	6447.00	0.50	3	2	605.0	4208.0
PG&E - Contra Costa	31	61.0	10.30	1.35	4.72	390.00	0.50	3	4	605.0	4208.0
PG&E - Contra Costa	32	137.2	53.66	24.89	8.26	405.00	0.50	3	5	605.0	4208.0
PG&E - Pittsburg	33	64.6	19.90	37.21	3.33	392.00	0.50	3	107	596.5	4209.6
PG&E - Pittsburg	34	137.2	20.90	25.84	4.27	371.00	0.50	3	41	596.5	4209.6
PG&E - Pittsburg	35	137.2	25.30	25.78	6.10	383.00	0.50	3	17	596.5	4209.6
PG&E - Hunters Point	36	61.0	10.12	2.04	4.98	475.00	0.50	3	6	565.0	4176.7
PG&E - Hunters Point	37	76.2	23.45	3.06	3.51	437.00	0.50	3	7	565.0	4176.7
PG&E - Potrero	38	91.4	16.06	4.20	3.35	366.00	0.45	3	14	554.5	4179.2
PG&E - Potrero	39	61.0	1.82	0.46	7.32	433.00	0.45	3	3	554.5	4179.2
Standard Oil	40	45.7	2.38	2.63	1.80	588.00	0.0	1	306	553.2	4199.1
Standard Oil	41	45.7	0.84	1.14	2.40	589.00	0.0	1	297	553.2	4199.1

factor that could be applied universally to the emission rates of all grid squares. The area source SO_2 emissions data were compiled by the Engineering Division of the Bay Area APCD by dividing emission sources into two categories; (above and below 100 feet). The total emissions of each pollutant were divided into two categories (above and below 100 feet). Since the data received for input to the emission file contained both point and area source data, the emissions from stacks taller than 100 feet were subtracted from the countywide total and source data for those stacks was input to the model as point source data. The remainder of the emissions (after subtracting the point sources) was distributed over the county based primarily on population density data and on industrial considerations by qualitative judgment. Area source data were also compiled from the NEDS files at EPA Region IX but those data were not used because (1) they represented countywide emissions and would have to be allocated to grid units similar to the way the data on tape had already been distributed, (2) they contained data from areas outside the Bay Area which could not be easily isolated from that which should properly be included with the Bay Area, and (3) the NEDS data were higher by a factor of 2 from the Bay Area APCD data.

5.2 SULFUR DIOXIDE MONITORING DATA

The sulfur dioxide data used for comparison with the model predictions represents data from either the sites operated by the Bay Area APCD or from those sites which are operated by industries which are required to operate monitors due to the current regulation as applied to sources emitting SO_2 in concentrations higher than 300 ppm. In all, 22 monitoring sites were used in this study. Table 6 lists the location of each station. Figures 4, 5, and 6 also show the locations of these monitors. The UTM coordinate grid lines at 10,000-meter intervals are shown on these figures. The locations of the wind sensing equipment are

Table 6. SO_2 Monitoring Locations

Location/Monitor Name	Operated By	UTM Coordinate		SO_2 Sampler Type
		X	Y	
Richmond Area				
1. Santa Rosa (ST)	BAAPCD	525.1	4254.7	W-G (1)
2. San Rafael (SR)	BAAPCD	542.3	4207.7	W-G
3. Garden Tract	Standard Oil of Cal.	554.8	4201.8	Philips
4. Castro	Allied Chemical	555.2	4199.7	Philips
5. Richmond (RI)	BAAPCD	555.4	4201.1	Continuous (2)
6. Napa (NP)	BAAPCD	561.6	4240.7	W-G
7. Vallejo (VA)	BAAPCD	567.1	4217.4	W-G
8. Rodeo	Union Oil of Cal.	564.1	4208.9	Philips
9. East Refinery	Union Oil of Cal.	566.6	4210.5	Philips
10. Crockett	Union Oil of Cal.	568.5	4212.0	Philips
Martinez Area				
11. Coast Apparatus	Stauffer	574.9	4208.4	Philips
12. Warehouse	Exxon	576.2	4214.4	Westhoff
13. Martinez Gun Club	Phillips Chemical	580.4	4208.1	Autometer
14. Chenery	Phillips Petroleum	584.0	4208.3	Autometer
15. Stanpac	Phillips Petroleum	584.9	4206.7	Autometer
16. McAvoy	Allied Chemicals	590.7	4210.3	Autometer
17. Pittsburg (PT)	BAAPCD	597.3	4204.4	W-G
San Francisco Area				
18. San Francisco (SF)	BAAPCD	551.1	4181.8	W-G
19. Sunnyvale (SU)	BAAPCD	557.8	4159.4	W-G
20. Fremont (FR)	BAAPCD	591.8	4154.6	W-G
21. San Jose (SJ)	BAAPCD	598.5	4133.0	W-G
22. Livermore (LI)	BAAPCD	608.6	4171.2	W-G

(1) W-G (West Gaeke) 24-hour bubbler
(2) Continuous monitor type not specified

also indicated on Figures 4, 5, and 6. The industrial monitoring sites operate continuously while some of those operated by the BAAPCD are continuous and others are operated every third day (which provides one integrated sample for that 24-hour period).

Each month the hourly average of the SO_2 concentrations measured at each of the industrial monitors is tabulated and sent to the BAAPCD. Copies of those monthly reports were furnished to GEOMET, and those hourly values were keypunched and loaded into the computer for processing and subsequent model validation.

The observed SO_2 concentrations for 1973 from the APCD monitors which are reported on a monthly summary were also keypunched and loaded into the computer for processing and model validation. A 24-hour average was computed for those stations which had hourly averages.

The observed SO_2 data, reported in pphm units, was converted into micrograms per cubic meter in order to compare with the predicted values which are in micrograms per cubic meter. The conversion factor used was 1 ppm equals 2860 micrograms per cubic meter.

The 1973 observed SO_2 concentrations are presented in Appendix B. The Technical Services Division of the BAAPCD publishes a monthly summary titled, "Contaminant and Weather Summary" from which our observed SO_2 data was extracted. A review of those monthly summaries indicates the BAAPCD standard for SO_2 of 4 pphm was exceeded once during 1973 when a 24-hour average concentration of 5.26 pphm was reported at the Richmond site on November 27. The 24-hour average concentration measured at each monitoring site used in this study is listed in Appendix B.

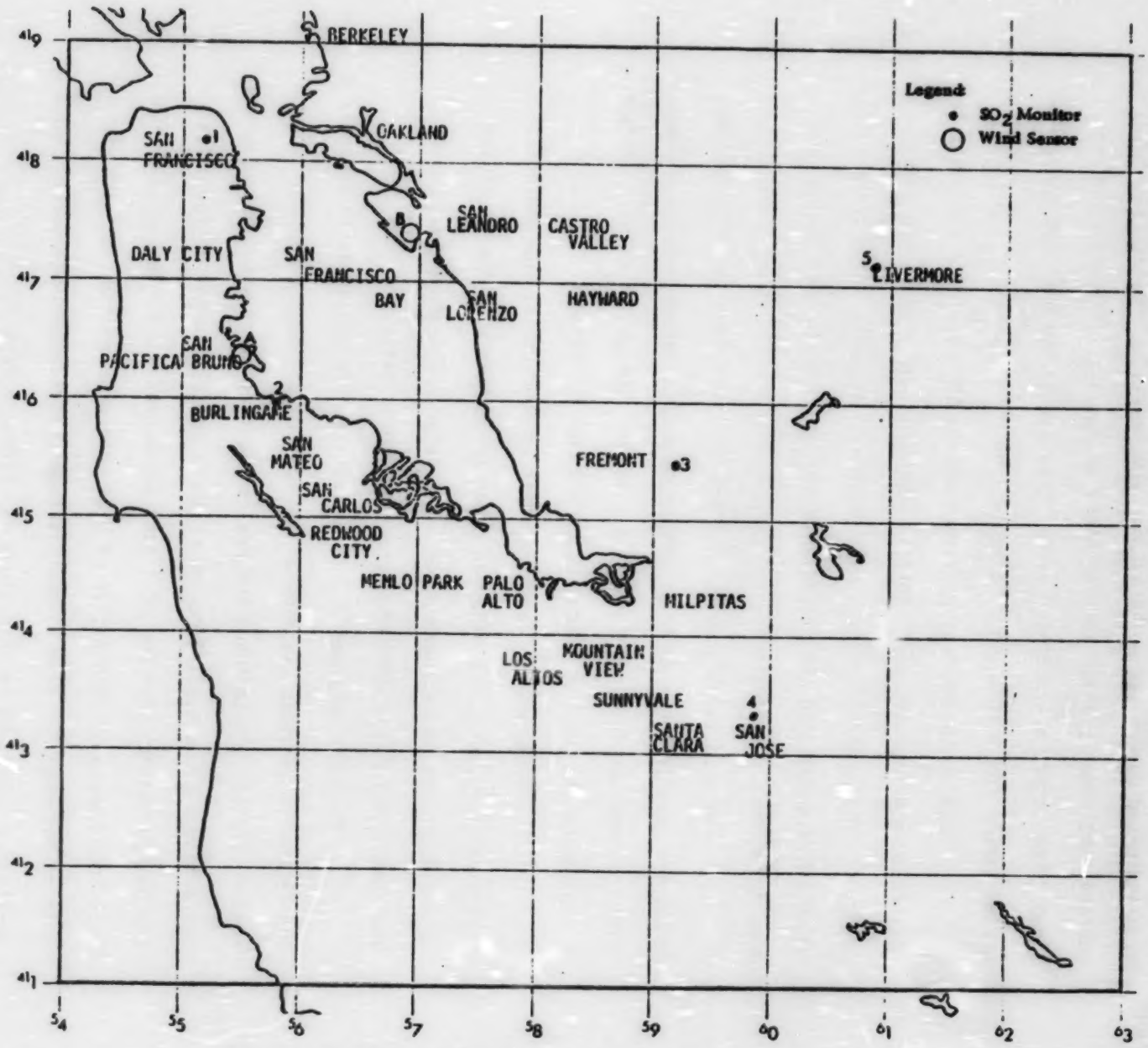

Figure 4. SO_2 Monitor and Wind Sensor Locations in the San Francisco Region

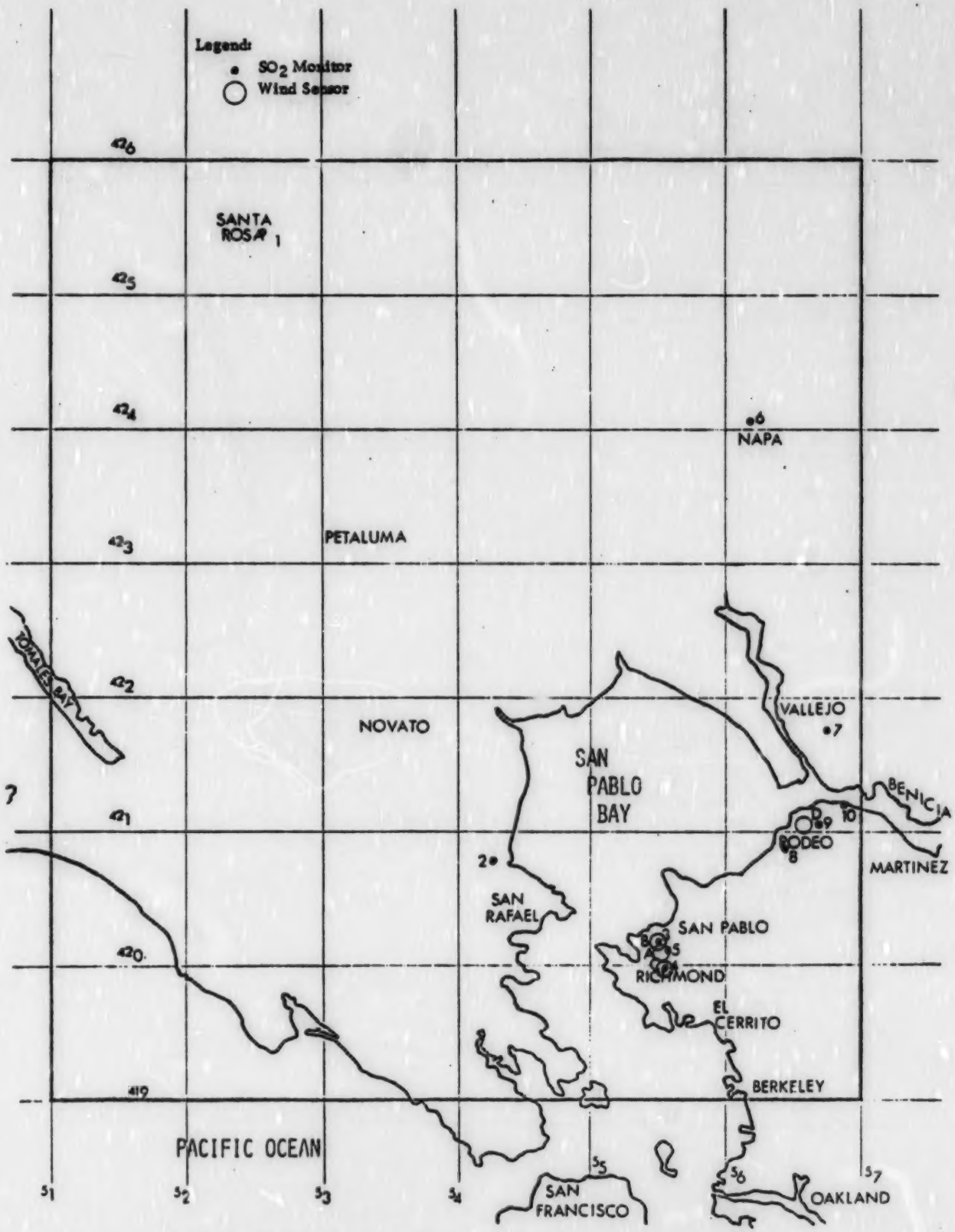

Figure 5. SO_2 Monitor and Wind Sensor Locations in the Richmond Region

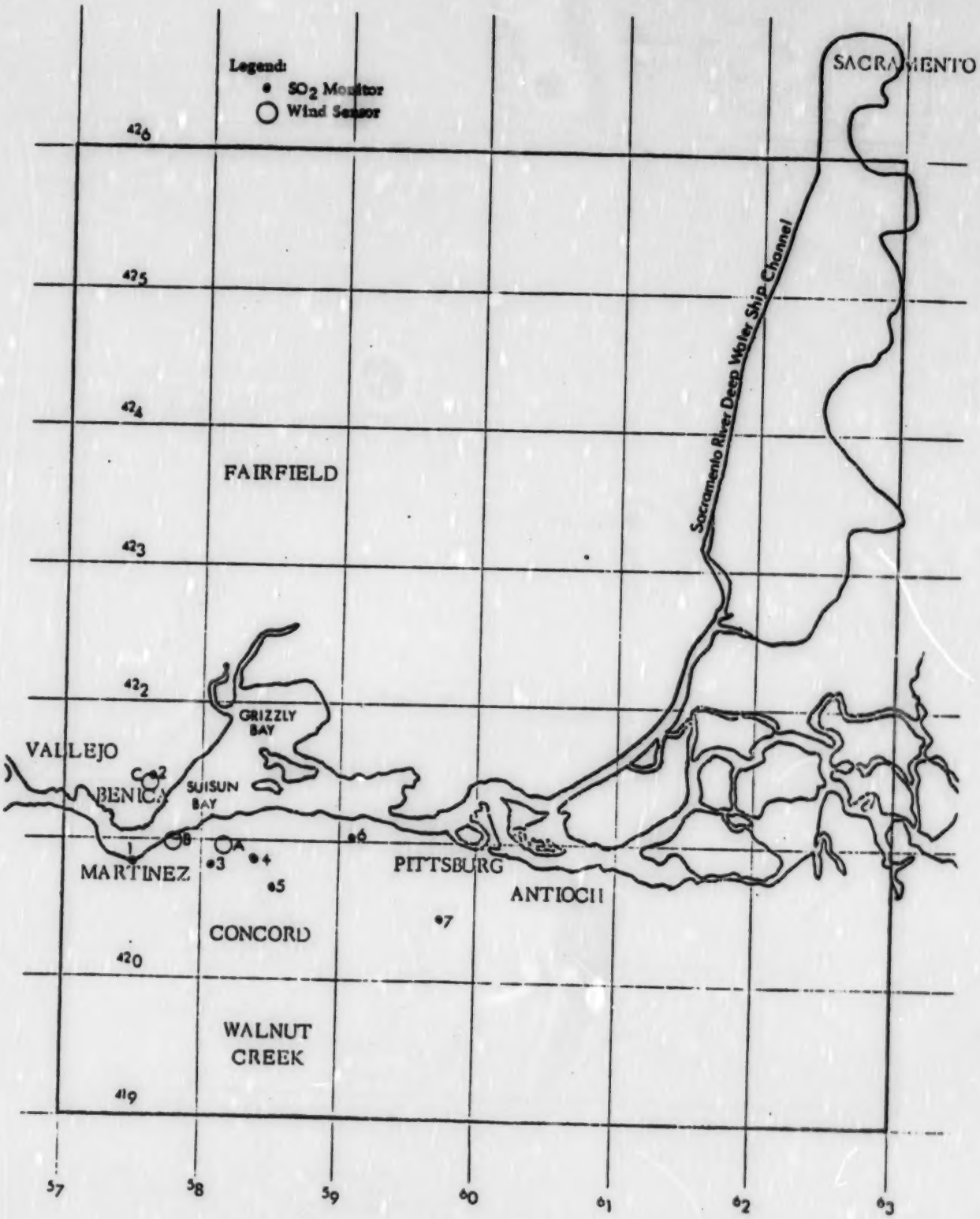

Figure 6. SO_2 Monitor and Wind Sensor Locations in the Martinez Region

Table 7. Calculated 24-Hour Average SO_2 Concentration

Station	Number of Times BAAPCD 24 Hour Standard was Exceeded	Maximum 24-Hour Average During 1973 (pphm)
Garden Tract	13	6.9
Castro	11	9.6
Rodeo	0	-
East Refinery	17	9.0
Crockett	17	6.4
Coast Apparatus	0	-
Warehouse	0	-
Martinez Gun Club	0	-
Chenery	33	14.2
Stanpac	19	6.9
McAvoy	4	6.1

Examination of the SO_2 monitoring data presented in Appendix B reveals that the 24-hour average SO_2 concentration measured at the industrial monitoring stations exceeded the state 24-hour standard 114 times during 1973. These exceedances were determined from averaging the hourly averages which were reported to the BAAPCD. However, of those 114 exceedances 14.2 pphm was the highest of the 24-hour averages. The seasonal effects on the occurrence of the exceedances is quite pronounced. There are 2 exceedances in the first quarter of the year (January, February, March), 36 in the second quarter (May, June, July), 64 in July, August, September and 12 exceedances in October, November, December. The BAAPCD standard for the 1-hour average of 50 pphm was not exceeded at any time. Table 7 indicates where those exceedances occurred and the highest exceedance value found.

5.3 METEOROLOGICAL DATA

Meteorological data used in this study included surface observations from San Francisco and Oakland International Airports, upper air observations from Oakland International Airport, and surface wind speed and direction from seven sites operated by the companies which maintained the SO_2 monitors. Table 8 lists the sites from which the meteorological data are obtained. The hourly wind data for the industrial sites were keypunched and loaded into the computer. A vector average of the wind speed and direction was computed for each of the three areas using those stations designated for each area in Table 8. An investigation of the wind data earlier in the contract led to the conclusion that the vector average of the stations in each region would provide a reasonable spatial average of the wind throughout each particular region. No single station could be identified which is representative of the mean values for the entire region.

Table 8. Meteorological Observation Locations

Location/Site Name	Data Received	UTM Coordinate	
		X	Y
Martinez Area			
Phillips Oil	Average Wind Speed and Direction - Hourly	581.4	4209.4
Stauffer Chemical	Average Wind Speed and Direction - Hourly	577.9	4209.9
Exxon Oil Co.	Average Wind Speed and Direction - Hourly	576.0	4214.0*
Richmond Area			
Standard Oil Co. (Gertrude)	Average Wind Speed and Direction - Hourly	555.0	4200.7
Standard Oil Co. (Garden Tract)	Average Wind Speed and Direction - Hourly	554.8	4201.8
Allied Chemical (Castro St.)	Average Wind Speed and Direction - Hourly	555.2	4199.7
Union Oil Co.	Average Wind Speed and Direction - Hourly	565.9	4200.4*
San Francisco Area			
San Francisco Int'l. Airport	Standard Surface Observations - 3 Hourly	554.6	4163.6*
Oakland Int'l. Airport	Standard Surface Observations - 3 Hourly and Radiosonde Data	569.0	4174.0*

Section 6.0

VALIDATION OF THE MODEL RESULTS

6.1 PRIOR VALIDATION STUDIES

The SCIM model used in this study has undergone validation testing in the past from applications using data from St. Louis and Chicago (Koch and Thayer 1971), New York City (Koch and Fisher 1973), Boston (Koch 1975) and Salt Lake City (Thayer 1974). Brief summaries of the results of those studies are presented in the following paragraphs. The model was initially developed and validated using data from St. Louis and Chicago by Koch and Thayer (1971). The results of the validation from that study are reproduced below:

1. Predicted long-term (month or season) concentrations averaged over several locations are in good agreement with observed concentrations.

2. Predicted long-term concentrations at individual locations show a root-mean-square-error equal to about half the mean and indicate a slight tendency to overestimate more often than underestimate observed concentrations.

3. Predicted short-term (one or two hours) concentrations at individual stations show larger deviations from observed concentrations than do the long-term predictions. However, over a period of a month, or a season, the overall distribution of predicted short-term concentrations closely approximates the distribution of observed concentrations.

4. Proportionate stratified sampling is an effective method of selecting a limited set of short-term periods which adequately define a representative distribution of short-term concentrations in a long-term period. One hour out of 24 is sufficient sample size for a three-month period if the selected hour is varied to include all hours of the day.

5. The calm, or light wind, case is not adequately treated by the Gaussian plume type of urban diffusion model. Further study of procedures for applying the model to this type of situation is needed.

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GEOMET

Subsequently SCIM was tested using data for New York City (Koch and Fisher 1973). In that study it was concluded that use of variable emission rates did not conclusively improve the model validity over use of mean emission rates; that the SCIM model and the Climatological Display Model (CDM) produce a smaller station-to-station RMSE (better prediction) than the Air Quality Display Model version of the multiple-source Gaussian plume model.

In evaluating proposed control strategies for the Boston area, using the SCIM model, the mean absolute difference between measured minus calculated concentrations was 2.4 μgm^{-3}, with a standard deviation of the differences of 26 μgm^{-3} using 14 stations for which observed and predicted 24-hour average values were available. When comparing the annual mean, the calculated annual averages for each station generally exceeded the measured values by a factor ranging from 1.5 when the observed concentration was as low as 10 μgm^{-3} to a factor of 1.14 when the observed concentration was 50 μgm^{-3} or greater.

In applying SCIM to the Salt Lake City area where the observed SO_2 concentration is quite low, the predicted values of SO_2 concentration were much higher than the very low observed levels; however, the validation in Salt Lake City is based on a limited amount of data. The similarity to the low levels of SO_2 observed in the Bay area is informative for application in this study.

In summary SCIM has been used in several large cities with results comparable to or better than other well known and commonly used models.

6.2 VALIDATION IN THIS STUDY

A useful method for determining the ability of the model to predict observed values for this study can be made by comparing the mean of the observed values to the mean of the predicted values. For each of the three regions defined in the study, 20 days were selected from the months of May, July, and August for which the SCIM-calculated SO_2 values would be compared to the observed SO_2 concentrations for model validation in the Bay area. The 21 stations used in this 20-day validation effort are listed in Table 9 and can be identified more completely by comparison to Table 7. The average ratio of predicted to observed concentration for all 21 stations is 1.0, which is an excellent agreement and in fact so good one must check to see if all data is just and valid. The ratio of the mean for each region is more instructive to look at to criticize the ratio of the predicted and observed concentrations.

The Martinez and Richmond regions are the areas of most interest to this study since most of the large sources are located in those regions. Table 9 shows the predicted to observed ratio for each regional average and for the stations within each region. In the Richmond region the model tends to overpredict the concentration and the regional average ratio is 1.4. In the Martinez region the station to station ratios are more uniform than in the Richmond region, however the regional average predicted to observed ratio is 0.4, which is not quite as good in the Richmond region. There is a consistent and general underprediction in the Martinez region but the ratios are fairly uniform and still quite good. Validation results were not as favorable in the San Francisco region where the predicted to

observed ratio is 3.9. It was mentioned in Section 7.1 the SCIM model validation in the Salt Lake City area was also not as favorable where SO_2 concentrations were very low. There may be several explanations for the over-prediction in areas where the SO_2 concentrations are low but no substantiated reasons have been established yet. The monitoring site at Burlingame has a remarkably high predicted to observed ratio of 12.2. This appears to be a legitimate value of a location where the average observed concentration is quite low. The low average at Burlingame is due to the predominance of zero values reported for that site on the days used in the evaluation. Overall, the performance of the model was quite good based on the 24-hour average SO_2 concentrations from 21 stations for a 20-day sample. Model performance was better in the Martinez and Richmond regions (the area of most concern) than in the San Francisco region.

Table 9. Means of Predicted and Observed SO_2 Concentrations for 20 Days

Region/Station	Predicted (μgm^{-3})	Observed (μgm^{-3})	Ratio $\left(\frac{\text{Predicted}}{\text{Observed}}\right)$
Richmond			
Santa Rosa	10.0	2.0	5.0
San Rafael	12.0	1.7	7.1
Garden Tract	50.2	66.8	0.8
Castro	99.5	47.3	2.1
Richmond	53.0	19.2	2.8
Napa	12.0	6.4	1.9
Valleto	23.5	8.6	2.7
Rodeo	16.0	7.4	2.2
East Refinery	49.6	56.9	0.9
Crockett	29.0	39.7	0.7
Region Average	35.5	25.6	1.4
Martinez			
Coast Apparatus	20.1	28.1	0.7
Warehouse	12.0	27.5	0.4
Martinez Gun Club	24.7	28.6	0.9
Stampac	17.7	70.9	0.3
McAvory	22.6	35.6	0.6
Pittsburg	14.1	23.0	0.6
Region Average	18.5	35.6	0.5
San Francisco			
San Francisco	7.7	1.6	4.8
Burlingame	4.9	0.4	12.2
Fremont	8.4	1.7	4.9
San Jose	8.0	3.5	2.3
Livermore	7.9	2.3	3.4
Region Average	7.4	1.9	3.9
Overall Bay Area	23.9	22.8	1.0

Section 7.0

EVALUATION OF THE STRATEGIES

The discussion presented in this section is based on the statistics computed from the predictions of the hourly average concentration at 120 receptor locations in the San Francisco Bay Area. The statistics for each location are presented in Appendix D which is included in Volume II - the data supplement of this report. The data in Appendix D includes, for each receptor point, the receptor location UTM coordinates, a frequency distribution of the 24-hour concentrations, the annual mean concentration, the geometric mean, the standard deviation from the mean, the geometric standard deviation, and an annual maximum 24-hour concentration based on extrapolation of the geometric mean and the geometric standard deviation. These statistics are given for the base condition (existing emissions) and for nine strategies (described earlier in Section 4.3) at each of the receptor locations. The data from Appendix D are summarized in Tables 10, 11, and 12. The annual mean and the highest predicted 24-hour average concentration for each strategy at each location is given in Tables 10, 11, and 12. The statistics developed for each of the receptor locations is based on 1135 hourly predicted values in the Martinez region, on 1336 hourly predicted values in the Richmond region, and on 1401 hourly predicted values in the San Francisco region.

In Tables 10, 11, and 12 and in Appendix D the base condition is identified as Strategy 1. Strategies 2 through 5 correspond to limiting SO_2 concentrations to a maximum of 300, 500, 1000, and 2000 ppm, respectively.

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Strategies 6 through 9 correspond to limiting sulfur content of fuel used in combustion sources to 0.3, 0.5, 0.7, and 0.9 percent, respectively. Strategy 10 indicates the expected concentrations if the steam electric generating stations were to switch from natural gas to using 0.5 percent sulfur fuel exclusively.

Table 10 summarizes the predicted concentrations for the Martinez region. In the Martinez region the highest calculated annual mean is 28 μgm^{-3} while the highest 24 hour mean in the base case (strategy 1) is 157 μgm^{-3}.

Table 13 shows the number of receptor locations where the 24-hour maximum calculated concentration will be reduced by a given percentage from the base case. In the Martinez region the average reduction of the calculated highest 24-hour concentration is 34 percent for all 40 receptors when 300 ppm is the maximum emission concentration allowed as in strategy 2. For strategies 3, 4, and 5, the average 24-hour high concentrations are reduced 28 percent, 10 percent, and 3 percent respectively. Strategies 6, and 7 have no noticeable impact on the 24-hour high concentrations. Strategy 8 there would be no increases greater than 15 percent over the base case. There were no changes in the calculated 24-hour high concentration in 36 of the 40 receptor sites due to Strategy 8, allowing fuel sulfur content to be 0.7 percent.

Strategy 9 shows an increase would occur at 8 receptor locations but the increase would be less than 10 percent over the base case at 4 receptor sites and there would be an increase at 4 receptor sites which would be between 11 and 50 percent over the base case. No change from strategy 1 is indicated for 32 of the 40 receptors.

Strategy 10 indicates how the SO_2 concentrations might be affected if 0.5 percent fuel were used at the power generating plants instead of natural gas. The Martinez region shows the most dramatic impact of such a switch of any of the 3 regions. The increase of the calculated 24-hour high concentration would average 195 percent more than the base case. But even with this amount of increase none of the receptor sites exceed the NAAQS for a 24-hour average (365 μgm^{-3}). The receptor site with the highest 24-hour concentration has 264 μgm^{-3} when considering strategy 10.

Table 11 summarizes the calculated SO_2 concentrations 33 locations in the Richmond region. The highest 24-hour average concentration in the Richmond region is calculated for the Castro St monitoring site, at 232 μgm^{-3} and the annual average at the same receptor site is 40 μgm^{-3}. All of the strategies designed to limit process emissions keep the calculated SO_2 concentration down below the air quality standard for the 24-hour average. The second highest 24-hour average concentration in the Richmond region base case is 208 μgm^{-3}, which is calculated for the receptor site where the BAAPCD operates a continuous SO_2 monitor. The BAAPCD monitor is located approximately 1 mile NE of the Castro St monitor. The 24-hour average and annual mean at all other receptor sites in the Richmond area are well below the NAAQS.

The effect of imposing the SO_2 emission limitations can be estimated from data presented in Table 14. Table 14 shows the number of receptor sites

which had the calculated SO_2 concentration reduced by the indicated amount, for each strategy. It can be seen from Table 14 the calculated concentrations are reduced by 10 to 50 percent at approximately half of the receptor sites for Strategies 2 to 5. Control of sulfur content of fuel would have only an insignificant effect at the receptor sites. The SO_2 concentration may increase up to as much as 49 percent at 1/3 of the sites in the Richmond region. However, even with increases in the high 24-hour concentration the SO_2 levels remain well below the air quality standard for 24-hour average and annual mean.

In the San Francisco region the highest predicted 24-hour average concentration for any of the 32 receptor locations is 61 μgm^{-3}, the highest annual mean is 9 μgm^{-3}. The calculated concentrations are well below the NAAQS for all sites in the San Francisco region. The high value of the calculated 24-hour average for each receptor site in the San Francisco region is shown in Table 12 along with the annual mean for each site.

The effect of imposing the sulfur emissions strategies is shown in Table 15. The calculated high 24-hour average is reduced by 10 to 25 percent at most of the sites in the region when Strategies 2, 3, or 4 are considered. With strategy 5 the reduction is less pronounced and the reductions occur in the range from 1 to 25 percent. No significant reductions occur using Strategies 6 through 9 in the San Francisco region. There would be an increase in the calculated 24-hour average at 9 of the 32 sites if the power plants were to use only 0.5 percent sulfur fuel.

Figures 7, 8, and 9 show the comparison of the isopleths of the annual mean concentrations using the base condition and the Strategy 2 condition. The base condition is shown with the solid isopleth lines while the Strategy 2 contours are dashed lines. The figures show that the areas covered by the indicated SO_2 concentrations are reduced to a greater degree, as expected, in the regions with the higher concentration than in the San Francisco region where the change in the area covered by the 5 μgm^{-3} contour is only slightly reduced.

An accurate evaluation of the impact of natural gas curtailment is difficult because the quantity of gas used by the customers is difficult to obtain and the curtailment schedule is a complex matter to try to program as a subtask to an air quality modeling study. In the Bay area gas curtailment is accomplished by scheduling the most severe cutback first to the customers which use the most gas and those customers which accept a more favorable rate if they accept the fact that gas supply may be interrupted from time to time. Smaller commercial and residential users of gas would face only a low probability of having gas service interrupted. Furthermore, the interruptions are not predictable and when interruption is made the areas cut off move from one area to another in order to distribute the interruptions uniformly. Pacific Gas & Electric Company uses five groups to categorize their customers to establish priorities for interruption of service. Residential and small commercial customers can expect

a less than 1 percent chance that gas service will be interrupted through the 1977-78 gas season while the customers which use more than 24 million therms per year may expect a 76 percent level of service in the 1975-76 season, 59 percent in the 1976-77 season and 47 percent level of service in the 1977-78 season. For purposes of this study the smaller users categorized in the air quality model as area sources will not be greatly affected by interruptions in gas service, the larger gas customers which would be affected more noticeably are modeled as point sources. Some assessment can be made of the effects of changing from gas to a higher sulfur fuel by looking at the changes in calculated concentrations at a receptor which is affected by a combustion source, i.e., look at Strategies 6 through 10 in Tables 10, 11, and 12. The most pronounced effect can be seen by comparing the calculated concentrations for Strategy 1 with Strategy 10. Strategy 10 is the case in which the power generating plants use no natural gas - but use 0.5 percent sulfur fuel oil. In the Martinez region most of the receptor locations reflect a higher 24-hour average and annual mean concentration due to natural gas curtailment at the power plants whereas the increases are fewer in number and magnitude in the Richmond and San Francisco regions. If some major policy change were made such that the gas to the smaller customers was not available then the source-receptor file (Appendix E) will offer some insight to the changes which may be expected in the air quality. Data in Appendix E show that the area sources contribute an average of 60 percent of the SO_2 to the annual mean concentration

at all the receptor locations evaluated in the Bay area. In the Martinez region, area sources were responsible for 45 percent of the annual mean concentration, in the Richmond region 62 percent of the annual mean is attributed to area sources and in the San Francisco region 74 percent of the calculated SO_2 concentration is due to contributions from area sources. Any anticipated change in SO_2 emissions due to area sources and the resultant effect on air quality may be approximated in a very general way using this information and imposing all the necessary caveats that go with making such a generalized assessment.

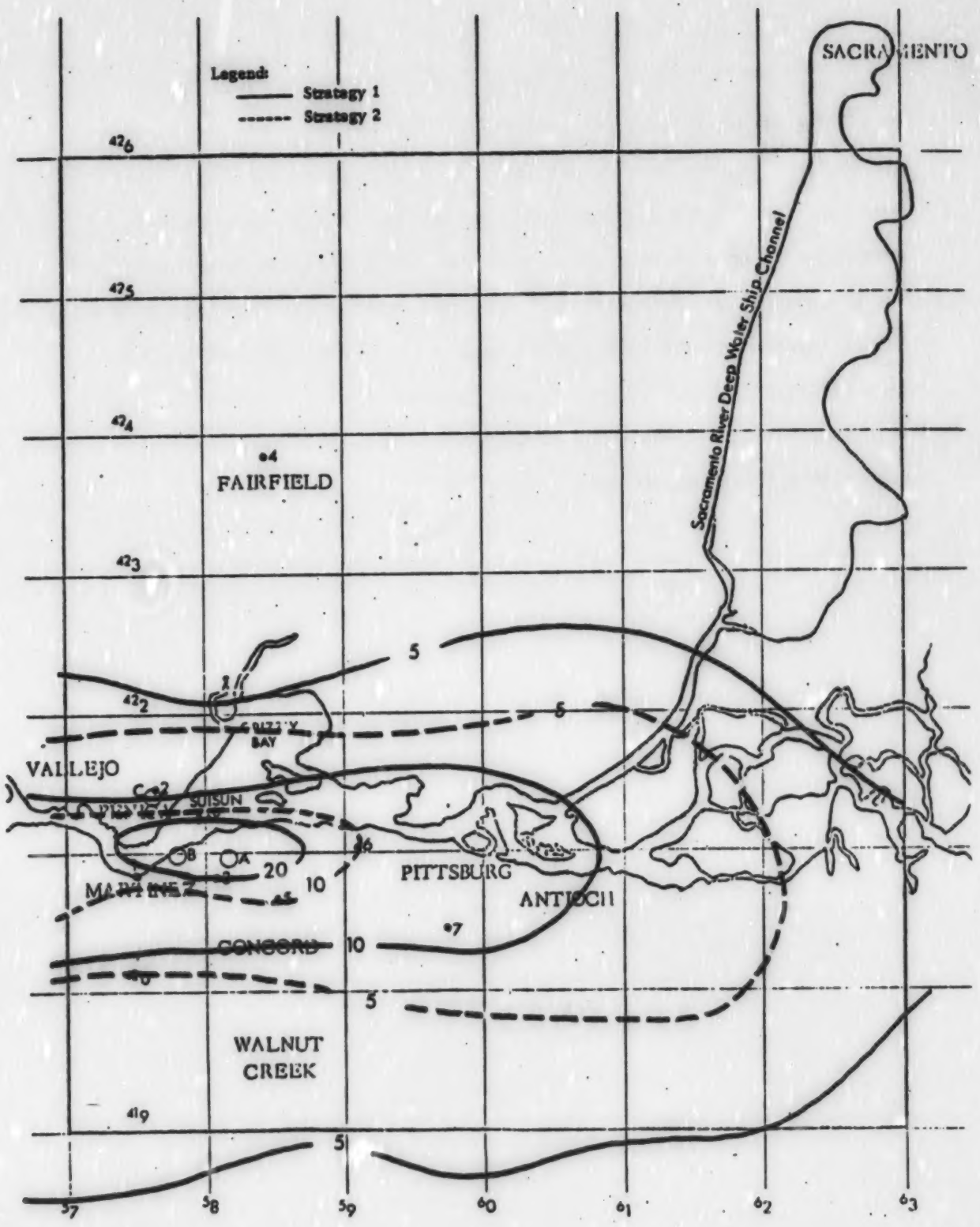

Figure 7. Isopleths of Annual Mean SO_2 Concentration (μgm^{-3}) in the Martinez Region

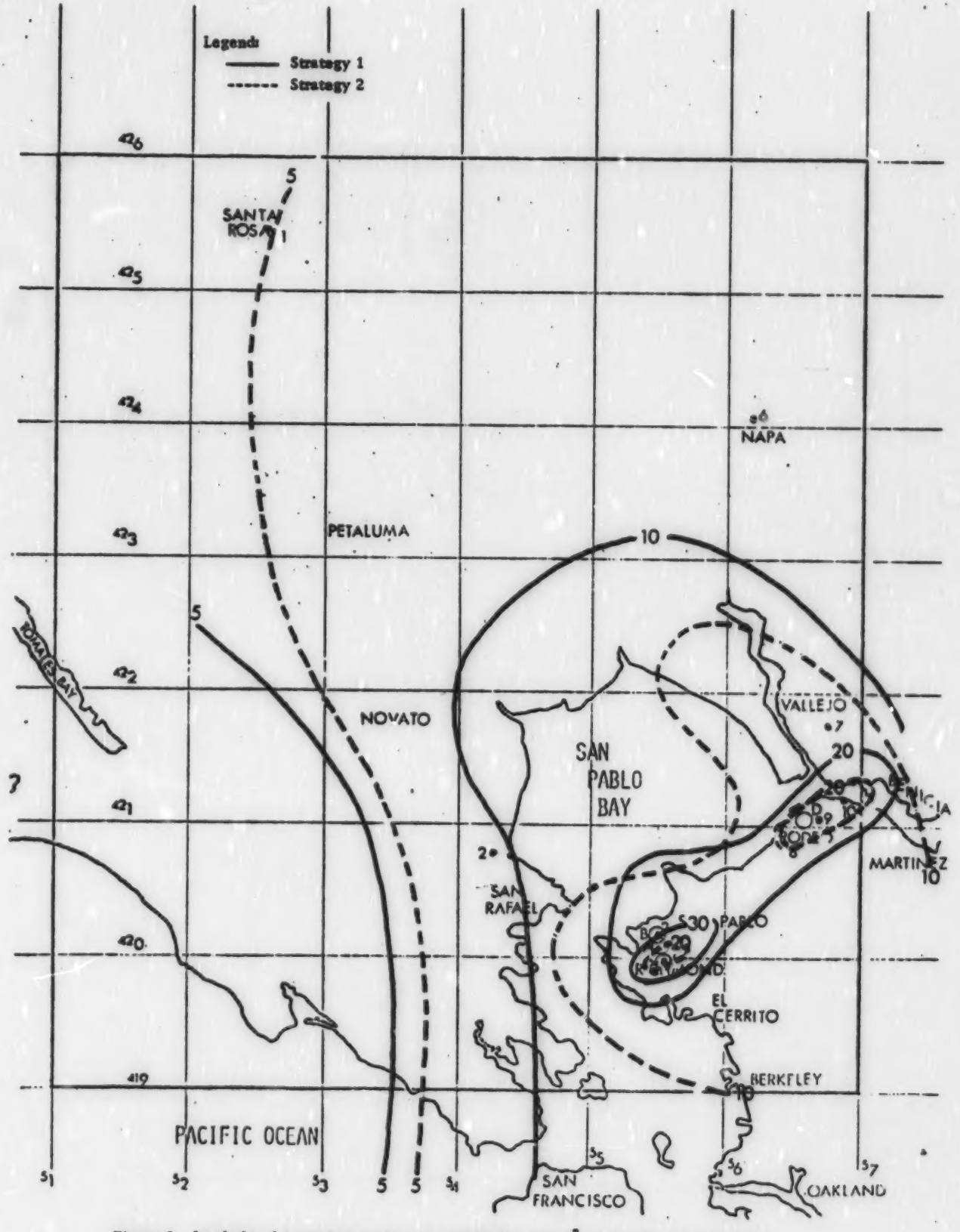

Figure 8. Isopleths of Annual Mean SO_2 Concentration (μgm^{-3}) in the Richmond Region

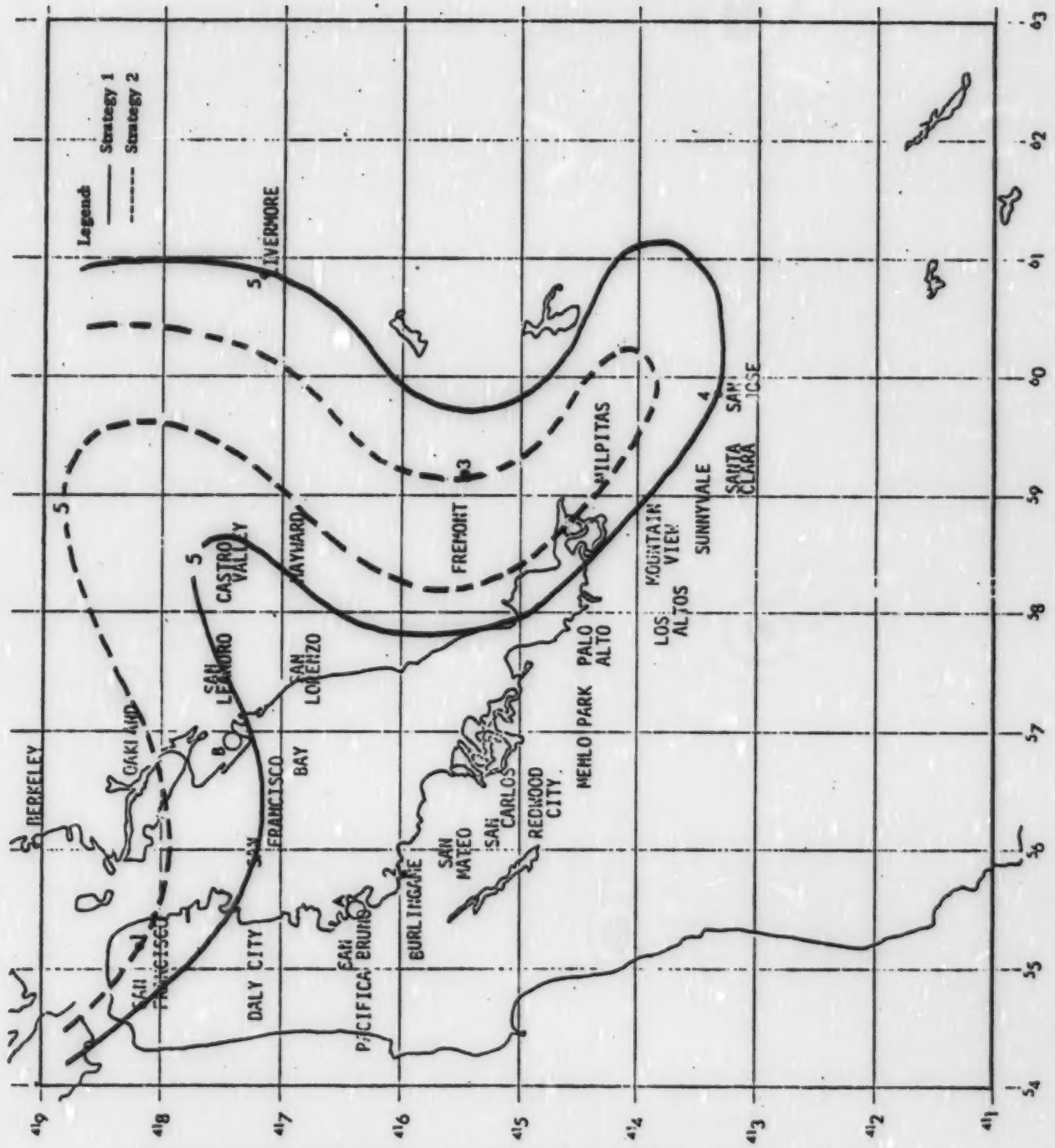

Figure 9. Isopleths of Annual Mean SO_2 Concentration (μgm^{-3}) in the San Francisco Region

Table 10. Predicted SO_2 Concentrations at Each Receptor in the Martinez Region (units = $\mu g/m^3$)

Strategy		1		2		3		4		5		6		7		8		9		10	
UTM		24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean
X	Y																				
574.9	4398.4	76	12	52	10	61	10	72	11	76	11	74	12	76	12	77	12	79	12	152	15
576.2	4214.4	111	20	41	8	61	9	110	10	110	10	111	11	111	11	111	11	111	11	111	11
580.4	4208.1	54	14	41	10	44	11	54	12	56	13	53	13	54	13	55	13	57	13	121	27
584.0	4238.3	60	3	29	2	35	2	60	2	60	3	60	3	60	3	60	3	63	3	60	3
584.9	4386.7	50	14	29	10	34	11	45	12	49	13	49	13	50	14	50	14	50	15	125	16
590.7	4210.3	63	21	35	10	40	12	49	17	62	20	63	21	63	21	64	21	65	22	253	25
597.3	4394.4	34	11	26	7	27	8	31	9	34	10	34	11	34	11	35	11	35	11	90	11
570.0	4190.0	51	6	26	5	30	5	47	5	51	5	51	6	51	6	51	6	51	6	51	7
570.0	4200.0	61	7	30	4	33	4	61	5	61	5	61	7	61	7	61	7	61	7	77	8
570.0	4210.0	88	17	54	15	55	15	56	16	88	17	88	17	88	17	88	17	88	18	182	20
570.0	4220.0	82	5	80	3	80	4	80	4	80	4	82	5	82	5	82	5	82	5	90	5
570.0	4230.0	76	2	76	1	76	1	76	1	76	2	76	2	76	2	76	2	76	2	77	2
580.0	4190.0	26	5	17	4	17	4	17	4	17	4	26	5	26	5	26	5	26	5	51	6
580.0	4200.0	19	6	15	4	15	4	16	5	19	5	19	6	19	6	19	6	20	6	50	7
580.0	4210.0	77	38	50	15	51	17	57	22	77	27	77	27	77	28	77	28	77	29	137	32
580.0	4220.0	98	8	34	5	42	6	64	7	98	8	98	8	98	8	98	8	98	8	94	9
580.0	4230.0	117	4	71	3	73	3	112	3	117	4	117	4	117	4	117	4	117	4	117	5
580.0	4300.0	27	1	15	1	18	1	26	1	27	1	27	1	27	1	27	1	27	1	27	1
590.0	4190.0	22	5	19	4	19	4	19	4	19	4	22	5	22	5	22	5	22	5	74	5
590.0	4200.0	25	6	19	4	20	5	21	5	22	5	23	6	23	6	24	6	24	6	31	7
590.0	4210.0	62	21	50	12	50	14	53	18	60	20	62	20	62	21	70	21	90	22	347	27
590.0	4220.0	82	8	39	5	48	6	72	7	82	8	82	8	82	8	82	9	82	9	81	10
590.0	4230.0	157	4	60	3	90	3	157	4	157	4	157	4	157	4	157	5	157	5	157	5
600.0	4190.0	23	5	20	4	20	4	26	4	30	4	23	5	23	5	23	5	23	5	24	5
600.0	4200.0	31	8	23	5	23	6	30	7	31	7	31	8	31	8	32	8	41	8	167	9
600.0	4210.0	72	38	46	10	47	11	66	14	72	15	72	15	72	16	72	17	77	18	364	32
600.0	4220.0	54	7	34	5	40	5	54	6	54	7	54	7	54	7	54	7	54	8	97	10
600.0	4230.0	41	5	35	4	36	4	40	5	43	5	43	5	44	5	47	5	60	6	236	7
610.0	4190.0	22	5	22	3	22	4	22	4	22	4	22	5	22	5	22	5	22	5	28	5
610.0	4200.0	27	8	16	5	19	5	23	6	26	7	27	7	27	8	27	8	30	8	70	9
610.0	4210.0	40	11	26	7	27	8	35	9	45	10	40	10	40	11	41	11	41	11	120	15
610.0	4220.0	126	8	70	6	88	6	126	7	126	8	126	8	126	8	126	8	126	9	127	11
610.0	4230.0	29	5	17	3	19	3	24	4	26	4	29	5	29	5	29	5	29	5	71	6
620.0	4230.0	62	2	36	2	43	2	58	2	62	2	62	2	62	2	61	2	63	3	80	3
620.0	4190.0	20	5	20	3	20	4	20	4	20	4	19	4	20	5	20	5	20	5	33	6
620.0	4200.0	38	8	19	5	20	5	24	6	26	7	28	7	28	8	30	8	29	8	48	9
620.0	4210.0	47	9	24	6	25	6	30	7	33	8	47	8	47	9	47	9	47	9	91	11
620.0	4220.0	72	6	40	4	49	4	69	5	72	6	72	6	72	6	72	6	73	6	73	8
620.0	4230.0	58	7	30	4	42	5	58	7	58	7	58	7	58	7	58	7	58	7	61	9
630.0	4210.0	33	2	22	2	24	2	27	2	30	2	33	2	33	2	33	2	33	2	70	3

Revised - 2/24/77

Table 11. Predicted SO_2 Concentrations at Each Receptor in the Richmond Region (units = $\mu g m^{-3}$)

Strategy		1		2		3		4		5		6		7		8		9		10	
UTM		24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean
X	Y																				
525.1	4254.7	33	6	28	5	29	5	30	5	31	5	33	6	33	6	33	6	33	6	33	6
542.3	4267.7	74	9	50	7	51	7	53	7	55	7	74	9	74	9	74	9	74	9	74	9
554.8	4266.8	158	22	69	14	72	14	78	17	85	18	158	22	158	22	158	22	159	22	158	23
555.7	4258.7	252	40	73	17	79	19	104	26	117	30	252	40	252	40	252	40	253	40	252	40
555.4	4251.1	208	23	82	14	91	15	120	17	140	18	208	23	208	23	208	23	208	25	208	24
546.6	4260.7	42	11	49	7	60	8	40	10	41	10	42	11	42	11	42	11	42	11	43	11
567.1	4247.4	86	17	89	16	89	16	84	17	84	17	86	17	86	17	86	17	86	18	88	18
564.1	4258.9	85	21	82	19	82	20	88	20	84	20	85	21	85	21	86	21	85	21	115	22
566.1	4240.5	181	26	118	24	138	24	181	25	181	25	181	25	181	26	181	26	181	26	181	27
568.5	4242.0	96	28	88	27	90	28	96	28	96	28	96	28	96	28	96	28	96	28	96	29
520.0	4190.0	75	3	50	2	60	2	63	2	67	2	75	3	75	3	76	3	76	3	77	3
520.0	4280.0	43	3	35	3	35	3	36	3	39	3	43	3	43	3	43	3	48	3	48	4
520.0	4260.0	37	4	27	4	29	4	32	4	34	4	37	4	37	4	37	4	37	4	71	5
520.0	4230.0	55	5	40	4	41	5	43	5	45	5	55	6	55	6	55	6	55	6	55	6
520.0	4210.0	62	7	48	6	49	6	51	6	52	6	62	7	62	7	62	7	62	7	60	7
540.0	4190.0	96	9	61	7	65	7	74	7	78	7	96	8	96	8	96	8	96	8	101	9
540.0	4280.0	50	7	43	6	43	6	48	6	48	6	50	7	50	7	50	7	50	7	50	7
540.0	4270.0	75	8	52	6	53	6	55	7	57	7	75	8	75	8	75	8	75	8	80	9
540.0	4250.0	58	9	48	6	46	7	48	7	49	7	58	9	58	9	58	9	58	9	71	9
540.0	4230.0	39	7	30	5	34	6	35	6	39	6	39	7	39	7	39	7	39	7	39	8
550.0	4190.0	64	9	37	7	38	8	40	8	44	8	64	9	64	9	64	9	64	9	64	11
550.0	4280.0	72	12	71	11	71	11	71	11	71	12	72	12	72	12	72	12	72	12	72	13
550.0	4260.0	67	13	38	8	38	8	36	9	35	10	67	13	67	13	67	13	67	13	91	14
550.0	4230.0	38	9	32	6	35	6	35	7	34	7	38	9	38	9	38	9	38	9	41	9
550.0	4250.0	67	10	42	8	42	8	43	9	44	9	67	10	67	10	67	10	67	10	67	10
560.0	4190.0	85	11	41	10	41	10	43	10	46	11	85	11	85	11	85	11	85	11	85	13
560.0	4280.0	68	14	42	10	42	11	46	12	48	12	68	14	68	14	68	14	68	14	68	15
560.0	4240.0	84	10	57	9	59	9	66	9	68	10	84	10	84	10	84	10	84	10	107	11
560.0	4220.0	70	12	48	11	48	11	48	11	49	12	70	12	70	12	70	12	70	12	70	13
560.0	4250.0	39	12	45	9	46	9	47	11	50	11	50	12	50	12	50	12	50	12	52	12
570.0	4220.0	120	15	110	9	112	11	116	14	119	15	120	15	120	15	120	16	120	16	120	16
570.0	4230.0	65	13	54	7	55	8	56	12	58	13	65	13	65	13	65	13	65	13	65	14
580.0	4250.0	42	6	36	6	37	6	39	7	42	7	41	8	42	8	42	8	42	8	41	8

Revised - 3/26/77

Table 12. Predicted SO_2 Concentrations at Each Receptor in the San Francisco Region (units = $\mu g m^{-3}$)

Strategy		1		2		3		4		5		6		7		8		9		10	
UTM		24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean	24-Hour High	Annual Mean
X	Y																				
555.1	4181.8	44	9	39	8	39	8	41	8	41	8	44	9	44	9	44	9	43	9	45	10
557.8	4159.4	34	6	30	4	34	4	34	4	34	4	34	4	34	4	34	4	34	4	37	5
591.8	4154.6	33	6	27	5	28	5	31	5	33	6	33	6	33	6	33	6	33	6	33	6
598.5	4133.0	57	6	57	6	57	6	57	6	57	6	57	6	57	6	57	6	50	6	50	7
608.6	4171.2	22	6	15	4	16	4	19	5	21	5	22	6	22	6	26	6	30	6	44	7
550.0	4160.0	15	1	12	1	13	1	15	1	15	1	15	1	15	1	15	1	15	1	16	1
550.0	4150.0	20	2	17	1	17	1	17	1	18	1	19	2	20	2	20	2	20	2	22	2
550.0	4140.0	28	3	24	3	24	3	25	3	25	3	26	3	28	3	30	3	29	3	30	3
550.0	4130.0	32	5	25	4	25	4	27	5	28	5	31	5	32	5	32	5	33	5	40	5
550.0	4120.0	46	9	36	8	37	8	39	8	41	8	46	9	46	9	46	9	46	9	46	9
560.0	4150.0	16	1	14	1	14	1	14	1	16	1	16	1	16	1	16	1	16	1	16	1
560.0	4140.0	26	2	23	2	23	2	23	2	23	2	26	2	26	2	26	2	26	2	26	2
560.0	4130.0	34	3	31	3	31	3	31	3	31	3	34	3	34	3	34	3	34	3	34	3
560.0	4120.0	30	5	30	4	30	4	30	4	30	4	30	5	30	5	30	5	30	5	31	5
560.0	4110.0	39	7	36	6	36	6	39	6	47	6	47	7	47	7	47	7	47	7	49	8
570.0	4150.0	29	2	26	2	28	2	28	2	28	2	29	2	29	2	29	2	29	2	29	2
580.0	4140.0	44	5	39	4	39	4	40	4	41	4	44	5	44	5	44	5	44	5	46	5
590.0	4150.0	61	6	61	5	61	5	61	5	61	6	61	6	61	6	61	6	61	6	61	6
590.0	4170.0	43	7	36	6	37	6	38	7	39	7	43	7	43	7	43	8	43	8	44	8
590.0	4180.0	35	7	27	5	28	5	31	6	32	6	33	7	33	7	33	7	33	7	33	7
600.0	4130.0	42	6	42	5	42	5	42	6	43	6	43	6	43	6	43	6	43	6	44	6
600.0	4140.0	30	5	25	4	25	4	26	4	27	5	30	5	30	5	30	5	30	5	30	5
600.0	4150.0	34	5	30	4	30	4	32	5	32	5	34	5	34	5	34	5	34	5	34	5
600.0	4160.0	60	7	50	6	52	6	55	6	56	6	60	6	60	7	60	7	61	7	61	7
600.0	4170.0	33	7	30	5	30	5	29	6	31	6	33	6	33	7	33	7	33	7	33	7
600.0	4180.0	32	6	22	5	25	5	30	5	32	6	32	6	32	6	33	6	33	6	33	7
610.0	4130.0	30	5	27	4	27	4	28	4	29	4	30	4	30	5	30	5	30	5	30	5
620.0	4140.0	50	5	34	4	38	4	45	4	47	4	50	4	50	5	50	5	50	5	50	5
630.0	4150.0	21	4	18	3	18	4	19	4	20	4	21	4	21	4	21	4	21	5	21	5
640.0	4160.0	17	3	8	1	10	1	16	2	17	2	17	2	17	2	17	2	17	2	18	3
580.0	4180.0	29	3	24	3	24	4	25	4	26	4	29	2	29	2	29	2	29	2	29	2
620.0	4190.0	23	4	20	3	20	4	20	4	21	4	22	4	23	4	23	4	23	4	32	5

Revised - 2/26/77

Table 13. Effect of Strategies 2-10 on Calculated 24-Hour High Concentrations
Martinez Region

Percent Change	Number of Sites Where Concentration Changed by Indicated Amount Due to Strategy								
	2	3	4	5	6	7	8	9	10
≥ 75	0	0	0	0	0	0	0	0	>200%, 13
50-74	5	1	0	0	0	0	0	0	>100%, 3
25-49	24	26	5	2	1	0	0	(3)	>50%, 4
10-24	7	9	12	3	0	0	(1)	(1)	>25%, 5
< 10	1	1	12	7	1	1	(3)	(4)	1-24%, 3
No Change	3	3	11	28	38	39	37	33	12

No parenthesis - decrease in calculated concentration
Parentheses - increase in calculated concentration

Table 14. Effect of Strategies 2-10 on Calculated 24-Hour High Concentration
Richmond Region

Percent Change	Number of Sites Where Concentration Changed by Indicated Amount Due to Strategy								
	2	3	4	5	6	7	8	9	10
≥ 75	0	0	0	0	0	0	0	0	(1)
50-74	5	5	2	1	0	0	0	0	0
25-49	9	7	7	7	0	0	0	0	(3)
10-24	11	12	13	10	0	0	0	0	(1)
< 10	8	9	9	10	1	1	1	1	(9)
No Change	0	0	2	4	32	32	32	32	19

No parentheses - decrease in calculated concentration
Parentheses - increase in calculated concentration

Table 15. Effect of Strategies 2-10 on Calculated 24-Hour High Concentration
San Francisco Region

Percent Change	Number of Sites Where Concentration Changed by Indicated Amount Due to Strategy								
	2	3	4	5	6	7	8	9	10
≥ 75	0	0	0	0	0	0	0	0	(2)
50-74	1	0	0	(1)	(1)	(1)	(1)	(1)	0
25-49	4	3	0	0	0	0	0	0	(1)
10-24	19	21	16	9	0	0	0	0	(2)
< 10	4		10	14, (1)	3, (1)	(1)	(2)	(6)	(4)
No Change	4	5	6	7	30	30	29	25	23

No parentheses - decrease in calculated concentration
Parentheses - increase in calculated concentration

Section 8.0

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APPENDIX A

EXISTING REGULATIONS REGARDING SULFUR DIOXIDE EMISSIONS

The pertinent portions of the Bay Area Air Pollution Control District, Regulation 2 have been copied and presented as Appendix A. This portion of Regulation 2 describes what the permissible concentration of SO_2 emission is and alternative precaution which must be undertaken if the SO_2 concentration exceeds the regulation.

§ 3120 SULFUR DIOXIDE

§ 3121 No **person** shall cause, let, permit, suffer or allow any **emission** of sulfur dioxide from sources other than ships which results in ground level concentrations of sulfur dioxide at any given point in excess of 0.5 ppm (vol) for 3 consecutive minutes or 0.5 ppm (vol) averaged over 60 consecutive minutes, or 0.04 ppm (vol) averaged over 24 hours, or any of the limits specified in Table 1. § 3121 shall not apply to the ground level concentrations occurring on the property from which such **emission** occurs, provided such property, from the **emission point** to the point of any such concentration, is controlled by the person responsible for such **emission**. *(Amended by Resolution 834, dated March 21, 1974.)*

§ 3122 Except as provided in § 3123, no person shall cause, let, permit, suffer, or allow the **emission** of gas containing sulfur dioxide from sources other than ships in excess of 300 ppm (vol). No person shall cause, let, permit, suffer, or allow the **emission** from a ship of gas containing sulfur dioxide in excess of 2200 ppm (vol) except when the ship is entering port from outside the District. All sampling of exhaust gases shall follow the techniques prescribed in Chapter 2, Division 8. For purposes of this section 3122, all sulfur present in gaseous compounds containing oxygen shall be deemed to be present as sulfur dioxide, and analyses of samples taken to determine the amount of sulfur dioxide in exhaust gases shall be made as specified in Chapter 1, Division 9. Tests for determining compliance with this secton 3122 shall be for not less than 15 consecutve minutes or 90% of the time of actual source operation, whichever is less. *(Amended by Resolution 834, dated March 21, 1974.)*

TABLE I

3121

MAXIMUM ALLOWABLE SULFUR DIOXIDE GROUND LEVEL LIMITS

SO_2 Concentration ppm (vol)	Total Cumulative Exposure Between Midnight and the Next Succeeding Midnight in Hours
Column 1	Column 2
1.5	0.05
0.5	1.0
0.3	3.2
0.1	9.6
0.04	24.0

(Amended by Resolution 635, dated November 5, 1970, and by Resolution 674, dated July 22, 1971.)

§ 3123 Emissions exceeding the limits established in § 3122 shall not constitute a violation of that section provided that all requirements of this section 3123, to wit, §§ 3123.1 through 3123.9, inclusive, are satisfied.

§ 3123.1 Such emissions shall not result in ground-level concentrations of sulfur dioxide exceeding the limits established by § 3121.

§ 3123.2 The person responsible for such emissions shall have notified the control officer in writing, prior to such emission, of his intent to operate under the provisions of § 3123. Such notice shall include information as to the location of all significant emission points, the location of the monitoring stations specified in §§ 3123.3 and 3123.4, and the nature of the source operations related to each such emission.

§ 3123.3 Such person shall provide at least three recording sulfur dioxide monitoring stations located in the area surrounding the source, which stations shall be operated in accordance with the specifications of Chapter 4, Division 8.

§ 3123.4 Such person shall provide at least one recording meteorological station equipped to record wind speed and wind direction.

§ 3123.5 Such person shall provide the necessary care and maintenance services so that the instruments will function properly and adequately record sulfur dioxide exposures in the area.

§ 3123.6 Such person shall provide to the control officer a summary of the data obtained from such instruments during each calendar month. Such summary shall be in such form and detail as will show the degree of compliance with § 3121, and the time, location, extent, and duration of any recorded violation of the provisions of § 3121; shall include data giving the total mass rate of emission of sulfur dioxide from the emission points specified in § 3123.2, and a detailed report of instrument performance and maintenance; and shall be submitted within the calendar month immediately succeeding the recording of the data.

§ 3123.7 Such person shall keep for a period of at least two years all records gathered as a result of this section 3123, and shall make these available to the control officer at his request. *(Amended by Resolution 635, dated November 5, 1970.)*

§ 3123.8 Such person shall examine at the time of each instrument maintenance check and in any case at intervals of no greater than every seven days instrument records taken pursuant to the requirements of this section 3123 to determine compliance with § 3121. Any recorded violation of § 3121 shall be reported to the control officer within the next normal working day after such examinations. *(Amended by Resolution 635, dated November 5, 1970.)*

§ 3123.9 Whenever the records indicate that a violation of § 3121 has occurred the person responsible for such emission must furnish evidence that proper action has been taken to prevent recurrence, or a violation of § 3123 will be deemed to have occurred and emission will be regulated by § 3122. When instrument records are not adequate to show compliance with § 3121 the control officer may specify the schedule to be followed for producing a satisfactory record history.

§ 3123.10 *(Repealed by Resolution 674, dated July 22, 1971.)*

§ 3123.11 *Repealed by Resolution 674, dated July 22, 1971.)*

§ 3124 All persons subject to §§ 3120, 3121 and 3122 may be required to install and maintain, at or within a reasonable distance before the emission point, sensing, indicating and recording equipment that will accurately sense, indicate and record minute by minute fluctuations of the volume of gases being emitted, and the presence and concentration of sulfur dioxide, subject to the conditions of § 3124.4 *(Added by Resolution 635, dated November 5, 1970.)*

§ 3124.1 The equipment required by Section 3124 shall be calibrated, maintained, serviced and repaired by the person responsible for the operation so that it will function and adequately sense, indicate and record the phenomena it is designed to sense, indicate and record. *(Added by Resolution 635, dated November 5, 1970.)*

§ 3124.2 The records of the measurements required by § 3124 shall be kept for a period of two years, and they shall be made available to the Control Officer at his request. *(Added by Resolution 635, dated November 5, 1970.)*

§ 3124.3 The person responsible for the operation shall provide to the Control Officer a summary of the data obtained from the equipment required by § 3124 during each calendar month. Such summary shall be in such form as is prescribed by the Control Officer. *(Added by Resolution 635, dated November 5, 1970.)*

§ 3124.4 The Control Officer may require that instrumentation prescribed by § 3124 shall be installed when he has reason to believe that emissions of sulfur dioxide exceeded those allowed by § 3121 or § 3122. *(Added by Resolution 635, dated November 5, 1970.)*

§ 3131 No person shall cause, let, permit, suffer, or allow, from any source operation manufacturing sulfuric acid using as a principal raw material any sulfur-containing material, any emission having a concentration of SO_3 or H_2SO_4, or both, expressed as 100% H_2SO_4, exceeding 0.04 grain per standard dry cubic foot of exhaust gas volume. *(Added by Resolution 635, dated November 5, 1970.)*

§ 3131.1 No person shall cause, let, permit, suffer, or allow, from any source operation manufacturing sulfur using as a principal raw material any sulfur-containing material, any emission having a concentration of SO_3 or H_2SO_4, or both, expressed as 100% H_2SO_4, exceeding 0.08 grain per standard dry cubic foot of exhaust gas volume. *(Added by Resolution 635, dated November 5, 1970.)*

CHAPTER 2 -- GENERAL REQUIREMENTS

§ 3210 SAMPLING FACILITIES. The person responsible for emission of air contaminants, from any emission point, for which emission limits are established in this regulation shall, upon request of the Control Officer, provide in connection with such emission point and related source operations such sampling and testing facilities as may be necessary for proper determination of the nature, extent, quantity and degree of air contaminants which are or may be emitted as a result of such operation. Such facilities may be either permanent or temporary and shall be suitable for determination consistent with the emission limits established in this regulation; and shall comply with all applicable laws and regulations concerning safe construction or safe practice in connection with such facilities. *(Amended by Resolution 635, dated November 5, 1970.)*

§ 3210.1 Where ambient air or source tests or any other data indicate that emissions of air contaminants from any emission point may be in potential violation of limits established in this regulation, the Control Officer may require the person responsible to monitor continuously that emission point or the ambient air for the specific contaminants or conditions (e.g., opacity) in potential violation. Such monitoring instruments may be either permanent or temporary and shall be suitable for determinations consistent with the emission limits established in this regulation; and shall comply with all applicable laws and regulations concerning safe construction or safe practice in connection with such instruments. *(Added by Resolution 635, dated November 5, 1970.)*

§ 3210.2 The equipment required by Section 3210.1 shall be calibrated, maintained, serviced and repaired by the person responsible for the operation so that it will function and adequately sense, indicate and record the phenomena it is designed to sense, indicate and record. *(Added by Resolution 635, dated November 5, 1970. Amended by Resolution 674, dated July 22, 1971.)*